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NOTES ON POLLINATION AND CROSS-FERTILISATION IN THE COMMON RICE PLANT, ORYZA SATIVA, LINN.

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I.—Introductory.

During the past two years a large number of varieties of rice, cultivated in the districts of Lower Bengal, have been grown on the Dacca farm, with the object of studying their characters in single plant cultures and of ascertaining to what extent, if any, natural cross-fertilisation takes place, as a correct estimation of this latter point and of the precautions likely to be necessary to keep varieties pure, is an essential preliminary to the work of successfully distributing seed of improved types. This preliminary work is necessary in the case of all crops, but particularly so in the case of a crop like rice, in which the number of cultivated varieties, differing frequently by most minute points of difference, is very large, and the risk of accidental mixture of seed very great, owing to the peculiar conditions under which rice is grown.

Though the results obtained up to date are far from complete, they have shown that while some types are much superior to others and self-fertilisation is the normal process, cross-fertilisation does undoubtedly take place and under certain circumstances may considerably affect the successful introduction of an improved type into any particular locality where other inferior types are commonly grown. This question of pollination and

cross-fertilisation in rice has not been studied in detail in India, and in the following notes it is proposed to give a preliminary account of our observations on the subject, as far as the districts of Lower Bengal are concerned.

II.—*Pollination.*

A superficial examination of the flower of rice would lead one to believe that cross-pollination by the agency of the wind was the normal method. Shortly after the opening of the glumes the anthers may be seen hanging downwards from their filaments in such a way as almost to preclude the pollen from reaching the stigma of the same flower if dehiscence has not already taken place before this pendent position is reached, and frequently also the two feathery stigmas may be seen protruding one on either side from between the open glumes. Though no work has hitherto been done in India on the subject, much has been done in other countries, and a brief summary of previous literature is given below. Knuth* states that the species is allogamous and that the anthers are still closed when they emerge from the glumes, and do not dehisce till after they have bent over and hang downwards. More recently a Japanese worker, M. Akemine,† has given a detailed account of the morphology of the flower and of the flowering of a race of swamp-rice, known as "Akaghé," occurring in Northern Japan. Only a summary‡ of this paper has been seen by us. According to the summary, the author discusses in detail the climatic factors affecting the flowering and setting of the grain, describes the method of pollination, and gives cytological details regarding the fertilisation process. He gives no cases of the occurrence of cross-fertilisation, and concludes, from observations and experiments on the flower, that self-fertilisation is what usually occurs, pollination according to the writer taking place just before the flowers open. Lastly, Fruwirth and Van der

* Hand-book of Flower Pollination, Vol. III, 1909, p. 521.

† "On the Flowers and Flowering of O. sativa," Agric. Gazette, Nôgyô-Sekai, 1910-11.

‡ Cf. Bot. Centralblatt. No. 41 of 1911. pp. 370-71.

Stok* summarize fully all the work done up to date, chiefly by the latter in Java, on the subject of rice-breeding in general, including the question of pollination and cross-fertilisation. According to these authorities, self-fertilisation is the usual process, but cross-fertilisation may not infrequently take place between neighbouring plants, and must be taken account of in all breeding work.

According to our observations on the Dacca farm, the actual process of pollination is as follows :—

The spikelets, or flowers, mature from above downwards in a fairly regular sequence, and in the case of any individual flower the opening of the glumes and pollination takes place, as a rule, on the same day as that on which it emerges above the level of the leaf-sheath if this happens before mid-day, or at latest in the course of the forenoon of the following day. In almost every normal case, dehiscence of the anthers and pollination take place practically simultaneously with the opening of the glumes, sometimes even before they open at all, and at the time of dehiscence the stigmas are still enclosed and the anthers still within the shelter of the glumes. Hence self-fertilisation appears to be the usual method. In the case of *Aus* varieties, which in Lower Bengal flower during the months of May and June, the opening of the glumes and dehiscence of the anthers commences usually between the hours of 7 and 8 A.M. and continues till about 10 A.M. when it stops for the day, but in the case of the *Aman* varieties which generally begin to flower in late October or early November, not till later in the forenoon, beginning usually between 9 and 10 A.M., and continuing till mid-day. The later time of day at which the flowers of the *Aman* varieties open is probably due to the much lower temperatures in October and November.

Immediately before the flowers open and dehiscence takes place it may be seen that the top of the anthers is just touching the concave roof formed by the glumes which are still closed,

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* Fruwirth, Die Züchtung der Landwirtschaftlichen Kulturpflanzen, B. V., 1912, pp. 36—51.

and if at this stage the glumes are gently pulled apart, the anthers may be seen to dehisce and the pollen to fall in showers on to the feathery stigmas within. It is probable that the pressure of the anthers—which at this stage are being pushed up by the rapidly elongating filaments from below—on the glumes, together with the slight shock caused by the opening of the glumes and the consequent access of air and sunlight, are the immediate causes which bring about dehiscence.

Immediately after dehiscence, the glumes diverge a little further apart, the filaments rapidly elongate till the anthers protrude about their own length above the tip of the glumes, and then bend slowly outwards and downwards so that the anthers ultimately assume a pendent position. But before this stage is reached, in every normal case the anthers have already lost almost all their pollen and pollination has taken place before they emerged at all.

Both the extent to which the flowers open and the length of time they remain open vary considerably, but we have not been able to discover any differences in varieties with regard to this. It appears to be largely due to atmospheric conditions at the time. In the warmer and moister months of May and June the flowers of the *Aus* varieties open earlier in the morning, but appear to open to a less extent, and to remain open a shorter time than in the case of *Aman* varieties which flower in the colder and drier months of October-November. According to our observations, the whole process from the time of the opening of the glumes and dehiscence of the anthers till the time when the latter assume the pendent position, occupies on an average only about fifteen minutes, in both *Aus* and *Aman* varieties, but in the case of *Aus* varieties the flowers seldom remain open for a longer period than half an hour in all, while in the case of *Aman* varieties they may remain open for periods varying from about an hour to an hour and a half. If the weather is wet and rainy at the time when the flowers should normally open, as is frequently the case when the *Aus* varieties flower, they may not open at all, or if they do, they often do not close again, and a large percentage of

such flowers set no grain. It is a matter of common observation that a far larger number of empty husks are to be found in the heads of *Aus* varieties than in *Aman* varieties, due probably to the wet weather which often occurs in Lower Bengal when the *Aus* rices commence to flower.

In about four days a whole inflorescence will ordinarily have been pollinated in the way described above.

III.—Cross-Fertilisation.

Though the above is the normal process, the method of pollination by no means precludes the possibility of cross-pollination taking place. It has been pointed out above that the stigmas are not infrequently to be seen protruding from between the open glumes, while the stamens have not lost all their pollen when they assume the hanging position, so that there is every possibility, should self-pollination have failed, of cross-pollination resulting, and we have collected evidence to prove that it is by no means unknown, and under favourable weather conditions, bright sunshine with a gentle breeze, possibly takes place to a greater extent than we have as yet been able to prove. It is practically certain, however, that such cross-pollination as does take place is confined to neighbouring plants in the same plot, and that the pollen of one plant seldom if ever succeeds in reaching the stigma of a plant more than a foot or two away.

In the following paragraphs an account is given of the evidence we have so far collected as to the extent to which cross-pollination has been found to occur.

In 1911 single plant cultures of 150 types of transplanted *Aman* varieties were grown at Dacca farm from single plants selected in the season 1910. No cases of splitting crosses were found in these, and all were passed as pure at harvest time, but in four plots a few variant plants were found. Subsequent examination, however, in the laboratory, of the seed of certain white-grained varieties, proved that in some, red-grained seeds were to be found which had escaped detection at harvest time, and possibly there were others which were not discovered. Six

such cases were found, and in each case as many red-grained seeds as could be picked out were sown and the seedlings transplanted separately in 1912, every precaution being taken to prevent accidental mixture. In three of the six plots the red seeds have given rise to a few white-grained plants, proving that these were heterozygous as regards seed colour.

To return to the variant plants mentioned above, seed of four of these, which it was suspected might be crosses, was carefully preserved, sown and transplanted separately in 1912, and all have given rise to a variety of types as described below :—

The first of these (labelled Ba 1), was found in a variety named Gobrabali, a coarse rice from Bakarganj, and differed from the type chiefly in having reddish-coloured awns. This in 1912 split into four types—

(1)	Red awns, two inner glumes at flowering time pale green with red tip, turning yellow when ripe, stigmas black ...	60
(2)	Red awns, inner glumes at flowering time dark green with red tip, turning mottled brown, stigmas black ...	13
(3)	White awns, inner glumes at flowering time pale green with no tip, turning yellow, stigmas white	19
(4)	White awns, inner glumes at flowering time dark green with no tip, turning brown, stigmas white	4

Ratio red awns to white awns, 3·17 : 1

The second (labelled R 20) was found in a variety named Ukulmadhu from Rajshahi. The parent plant had a small, fine grain, the two small outer glumes yellow, and the inner glumes yellow with brownish coloured apex. This in 1912 split into three main types—

(1)	Small outer glumes yellow, inner glumes at first green with reddish tip, turning yellow with reddish tip, stigmas purple	5 noted.
(2)	Ditto, but with stigmas white	6 „
(3)	Small outer glumes coloured reddish-brown, inner glumes at first reddish with no tip, turning black, stigmas white ...	2

The only obvious difference between types (1) and (2) in this case lay in the colour of the stigma which can be accurately determined only before pollination has taken place. Unfortunately

the plot was not examined in detail till after flowering was almost over, and the colour of the stigma could be determined in only a small number of plants.

The third and fourth examples will be treated together. These were red-grained plants picked from white-grained plots, the red-grained plants in both cases being otherwise almost indistinguishable from the remaining white-grained plants in the plots. The first of these (labelled M 1) was found in a variety named Aman paddy from Mymensing, and the second (labelled B 15) in a variety named Bankalam from Bogra. These both split in 1912 into red and white-grained plants, otherwise almost indistinguishable except for grain colour, in the proportions given below—

1. M1, red-grained, 1911	... 1912, red-grained	... 145	ratio.	
	white-grained	... 55	2·6r. : 1w.	
2. B15, red-grained, 1911	... 1912, red-grained	... 132	ratio.	
	white-grained	... 68	1·9r. : 1w.	

Besides these four cases, much further evidence has been afforded by a series of Dinajpur varieties started from single plants selected in 1911. The seed of these varieties was collected from Dinajpur, partly from cultivators and partly from the Bazaars, and all were very mixed. In 1911, eighty-six single plants were selected from these Dinajpur plots and these were sown and transplanted separately in 1912 and no fewer than seven, or a percentage of 8·15, have given rise to a mixture of types. These are described below in detail.

In the first (labelled D 28), the parent plant had the small outer glumes coloured reddish-brown, and the inner glumes yellow with a dark apex. This in 1912 split into the following four main types :—

(1) Outer glumes coloured reddish-brown, inner glumes at flowering time green with red tip, turning yellow with dark tip, stigmas black... 2 noted.
(2) Ditto with stigmas white ... ... 6 "
(3) Taller, more robust plant, outer glumes coloured reddish-brown, inner glumes at flowering time reddish, turning black, stigmas black ... 2
(4) Ditto with stigmas white 1

As in the case of R 20 described above, here again it was too late to determine accurately the stigma colour in types (1) and (2), the only obvious point of difference between them, when the plot was examined, except in the cases noted.

In the second (labelled D 6), the parent plant had a red grain and in 1912 split into four main types, two with red and two with white grains, as noted below.

D 6—Red-grained, 1911.

(1) Reddish leaf-sheaths and stem above nodes, grain white ... 14.	(2) Ditto, grain amber ... 1.	(3) Green leaf-sheaths and stems, grain red of various shades ... 43	(4) Ditto, grain white ... 26.

In the third (labelled D 7), the parent was red-grained, and split into three main types, two with red grains and one with white, in the proportions given—

1. Glumes yellow, grain red 50
2. *Glumes mottled brown, grain red* 34
3. Glumes mottled brown, grain white 13

The remaining four Dinajpur examples are similar to those of M 1 and B 15 described above, *viz.*, red-grained parent plants splitting into red and white-grained offspring, almost indistinguishable except for the colour of the grain. The details of these four cases are as follows :—

Parent 1911.	*Offspring 1912.*		*Ratio R. : W.*
Red-grained.	Red-grained.	White-grained.	
D 17 ,, ...	72	21	3·4 : 1
D 18 ,, ...	72	24	3 : 1
D 35 ,, ...	51	21	2·42 : 1
D 38 ,, .	68	32	2·12 : 1

From a perusal of the above figures, together with those of M 1 and B 15 quoted above, it would seem that as regards colour of grain segregation is taking place in the simple Mendelian ratio of 3 : 1.* Cross-fertilisation experiments are in

* Cf. Van der Stok, l. c., p. 49.

progress with the object of verifying this and also of determining the mode of inheritance of certain other characters.

In addition to the examples described above of undoubted splitting crosses, stray variant plants have also been found in twelve of the 1912 pure line plots started from single plants selected in 1910, and in fifteen of the 1912 Dinajpur series started from single plants selected in 1911, amounting to about fifty in all. Some of these may prove to be accidental mixtures but some cannot be matched with any of our other types, and have all the appearance of being the F_1 generation of crosses which must have taken place within our area in 1911. Seed of all these is being preserved and will be sown in 1913 and the results noted.

From the above cases there is reason to believe that natural crossing in rice is more common than was at first supposed. Moreover, under the conditions in which rice is grown by the cultivator, whose varieties are never free from mixtures, it would probably take place to a considerably greater extent than in our area at Dacca. Even if it did not occur to any greater extent than the cases cited would indicate, it would be quite sufficient to account for the extraordinarily large number of types which are to be found, when one takes into consideration the extent and great antiquity of the cultivation. Certain facts also which have been brought to our notice lend further evidence to this belief. For example, a cultivator from the neighbourhood of Chandpur recently informed us that on his own land within the past twelve years the number of distinct types to be found in his fields has increased from eight or ten to almost a hundred, although he has imported no new varieties.

The main conclusions to be drawn from the above results are :—

1. That in Lower Bengal under favourable conditions cross-fertilisation may take place in rice to an extent which may be provisionally estimated at about 4 per cent.

2. That this cross-fertilisation takes place wholly through the agency of the wind and would seem to be effective only between flowers of adjacent plants to a radius of a few feet.

3. That as regards certain characters at least, *e.g.*, grain colour, segregation along Mendelian lines appears to take place.

4. That so long as seed of a variety is kept free from accidental mixture there is no risk of contamination from cross-fertilisation, but that if seed gets mixed, cross-fertilisation will undoubtedly take place between adjacent plants in a plot and to an extent sufficient in a few years' time to reduce a variety to a number of splitting types. Hence the imperative necessity of taking every precaution to keep seed of varieties free from accidental mixtures.

DACCA,
10th January 1913.

A SCLEROTIAL DISEASE OF RICE.

BY

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RECENT investigations in plant pathology have shown that a not inconsiderable number of the diseases of plants are to be attributed to the ravages of sclerotial fungi. Considering the habitat of these parasites it is not surprising to find that tuberous crops (*e.g.*, potato, carrot, beetroot) seem peculiarly liable to attack, the disease in such cases being usually known as "root rot." In other cases, however, the host plant is attacked in the seedling stage, the symptoms closely simulating the "damping off" due to Pythium and its allies. Of sclerotial fungi, which cause such diseases, one of the best known is *Rhizoctonia*, to which the "root rot" of many tubers, as well as the "damping off" of certain seedlings, is to be attributed. There has, however, recently been detected in India a disease of rice, due to the attack of a sclerotial fungus, which seems to present some distinctive feature in its effects upon the host plant.

The fungus is known as *Sclerotium Oryzæ*, Catt., and was first described by Cattaneo (2), in 1879, as the cause of extensive damage to the rice crop in Novara and Lombardy. His description was restricted to the morphology of the fungus on the rice plant and the symptoms of disease in the crop; as, however, culture work and inoculations were not attempted, adequate proof of the parasitic nature of the fungus was not obtained. Since the work of Cattaneo the fungus has also been discovered in Japan by Miyake (7), and has, within the past year, been collected in India.

Sclerotium Oryzæ is not, however, the only member of this genus which has been recorded as a disease of paddy. *Scl. glumale*, Ces., is known to attack rice in Borneo, while a new species, *Scl. irregulare*, is stated by Miyake to be the cause of some loss in Japan. Both these can easily be distinguished from *Scl. Oryzæ* by the size of the sclerotia. The former has been found on paddy at Noakhali, Eastern Bengal, but does not appear to be of any economic significance in India.

The genus *Sclerotium* was founded by Tode (11) in 1790, and, at present, includes a number of species of which the fertile stages are known in only a few cases. In 1816 Esenbeck (3) described six of the more important species with figures; he also includes *Thanatophytum Crocorum* (*Rhizoctonia Crocorum*) and *Erysibe suffulta* as near relatives of this genus. In a work published a few years later Fries (4) mentions fifty species and classifies them into four tribes, a sub-division which has persisted to the present day. It is interesting to note that he discards the name *Thanatophytum* for the more modern one of *Rhizoctonia*. In 1869 an enumeration of species peculiar to the Rhine district was given by Fuckel (5): an earlier publication by Kühn contains, however, more interesting matter. Kühn (6) gives some account of the work of Leveille and Tulasne (12), published a few years previously, by which the connection between *Sclerotium Clavus*, D. C., and *Claviceps purpurea*, Tul., was established. He also mentions that other species of the genus *Sclerotium* have their perfect stages among the *Clavariaceæ*. It is, of course, now well known that the original genus *Sclerotium* of Tode is an artificial one, the different members of which are really the sterile forms of widely separate fungi. *Agaricaceæ*, *Polyporaceæ*. *Clavariaceæ*, *Hypocreaceæ* and *Pezizaceæ* are the groups among which the fertile stages of different species of *Sclerotium* are to be found.

The Disease in the Field.

In India the first collection of *Scl. Oryzæ* was made at Noakhali. About a year later, in December 1912, fresh material

was obtained from localities as widely separate as Mandalay, Samalkota and Pusa; the external symptoms of disease were in all cases essentially the same. Infected plants can usually be distinguished from their healthy neighbours by the phenomenon of "tillering," that is to say, the development of fresh green shoots from adventitious buds at the base of the infected culm (Pl. I, Fig. 1). The infected culm gradually turns yellow and dies; any grain which it bears is light and poorly developed, in fact, there is usually nothing within the glumes. The most distinctive feature, indeed, the easiest means of detecting infected plants in the field, is the "tillering" from the base. In Pusa the disease does not make its appearance until the paddy crop is fairly well advanced; hence, even supposing that the fresh shoots remain free from the fungus, an unlikely event, there is no possibility of their producing any grain. It is the loss of grain which constitutes the most serious damage due to this fungus. In Burma the disease is one of the causes producing the condition known as "gwa-bo"; as, however, a number of insect diseases of paddy are included under this name, it is difficult to ascertain the precise amount of damage due to the fungus. The collective damage done by the combined insect and fungus attack is stated to run into hundreds of lakhs of rupees annually. Miyake in his description of the disease in Japan says: "Durch diese Parasitierung wird die Bildung der Reiskörner unvollständing, daher ist der Schaden sehr-gross." He does not appear to have observed the phenomenon of "tillering," a fact which Cattaneo also overlooked.

If a diseased culm is split longitudinally the basal portion is found to be infested with the fungus. The hyphæ form a dark greyish weft within the hollow stem, and small black sclerotia can be seen dotted all over the inner surface (Pl. II, Fig. 1). Sometimes the base of the culm is quite free from the fungus and the attack begins at a node some distance up the stem. A transverse section through an infected culm shows that hyphæ and sclerotia are not only present on the inner surface of the stem, but that the hyphæ penetrate the cells, and sclerotia are even

formed in the intercellular spaces between the main vascular bundles. This is clearly shown in Pl. III, Fig. 1. The section shows only the inner portion of the stem; a young sclerotium can be seen in one of the larger air cavities and the collapsed nature of the innermost layer of cells, in the vicinity of the two larger sclerotia, is apparent. In some of the cells hyphæ are distinctly visible: they are, however, more clearly shown in Pl. III, Fig. 2, from the same section. At first sight the sclerotia strongly resemble that of *Rhizoctonia Solani*, Kühn; they are, however, considerably larger and have a distinctly smooth shiny surface. In section the younger sclerotia appear to consist of fairly small parenchymatous cells, the outer cells being more or less definitely arranged in concentric layers. (Pl. III, Fig. 1). In fact, at this stage, there is a distinct differentiation into cortical and medullary zones. In the more mature sclerotia the differentiation into cortex and medulla is not so apparent, while the cell walls are thicker and of a sharp black colour (Pl. III, Fig. 3).

Cultures.

From diseased plants, such as those just described, cultures were obtained on agar. It may be stated here that in all cases, whether the cultures were made from hyphæ or sclerotia, and whether the material came from Burma, Samalkota or Pusa, the same fungus was obtained in culture. Cultures were made on media of widely different composition, and, in some cases, the nature of the nutrient substratum was not without influence on the character of the fungal growth.

Growth appeared to be most vigorous on glucose agar. An infection upon this medium resulted in a copious development of white hyphæ, followed, after five or six days, by the appearance of sclerotia. The sclerotia are at first visible as minute circular spots of a greyish colour; subsequently they become black and shiny, exactly resembling those found in the rice plant. The hyphæ are of the usual type, the cells being about 4—6μ broad and 150—350μ long, they contain numerous oil globules and

frequently branch. A transverse septum occurs at the point of origin of a branch and not some distance from it (Pl II, Fig. 11, cp. *Rhizoctonia*). The sclerotia are roughly circular and vary in diameter from 150—500μ. They arise from a plexus of interlacing hyphæ, which continue to branch and intertwine until a small spherical compact mass is formed. For a time the young sclerotium increases in size by the adhesion of fresh branches to the periphery ; ultimately, the cell walls turn black and all further growth ceases. At this stage the interior of the sclerotium has a very definite parenchymatous structure, and it is almost impossible to discern that it has been formed by interweaving hyphæ ; a thin layer of loosely intertwined hyaline hyphæ can, however, be seen investing the exterior. Not infrequently several sclerotia become united, forming an incrustation on the medium resembling a stroma : this was particularly common in cultures on maize meal.

In culture upon glucose agar, at an early stage, before the appearance of sclerotia, the mycelium along the edge of the agar appears black. An examination of the hyphæ at this region shows that they are more or less smoky coloured and of very irregular shape (Pl. II, Fig. 5); they frequently terminate in curious appendages. These appendages may consist of one or more cells ; they are very much darker in colour than the cells of the hyphæ, but resemble them in their irregular form (Pl. II, Fig. 6). In some cases the parent hypha was attached to the centre of the appendage in such a way that the latter was borne in a peltate manner (Pl. II, Figs. 7, 8). Infection upon glucose agar from these hyphæ and appendages produced cultures of the normal type resembling the parent culture. The fact that these structures are produced along the edges of the agar, in contact with the glass, suggested that they might be appressoria. If this is the case, it is not easy to understand why their formation should be restricted to one sort of agar medium ; in no case were they produced upon anything but glucose agar.

Infection upon nutrient agar containing extract of paddy grains gave rise to a rather different habit of growth. The

hyphæ at first spread over the surface of the agar, and slowly turn a brownish colour where they are in contact with the nutrient medium; the aerial hyphæ, however, remain white. Sclerotia arise first upon the surface of the agar, but, ultimately, may be found imbedded in it at various depths. At a level of about ¼ inch below the surface of the agar the hyphæ form a dense brownish black layer, which, upon examination, is seen to consist of an enormous number of chlamydospores. These chlamydospores are formed by the segmentation of the hyphæ into a number of short thick barrel-shaped cells. They possess thick black cell walls and contain food reserve in the form of oil drops (Pl. II, Fig. 9). Germination gives rise to a culture of the normal type.

Growth upon the special medium of filter papers was slow and produced nothing but hyphæ and sclerotia. The same may be said of French bean agar; in this latter case the fungus seemed to remain entirely superficial. Upon oat juice agar growth was very similar to that upon rice agar; in fact, it is difficult to distinguish between cultures of the same age upon these two media. Upon Lima bean agar the fungus gave rise to a curious red pigment. This developed about three days after infection and slowly spread down the tube following the growth of the hyphæ (Pl. I, Fig. 3). Growth upon maize meal was particularly vigorous, a dense white mycelium being formed in about 12 hours, followed by an abundant production of sclerotia. Here, again, the growth of the fungus is characterised by the production of red pigment in the meal.

The red pigment is strictly confined to the medium on which it is produced. If an infection is made from a culture upon Lima bean agar to glucose agar there is a faint reddening of the glucose agar just at the seat of infection, but this speedily dies away and does not spread down the tube. The production of the pigment is obviously the result of the changed metabolism conditioned by the alteration in the nutrient substratum.

Inoculations.

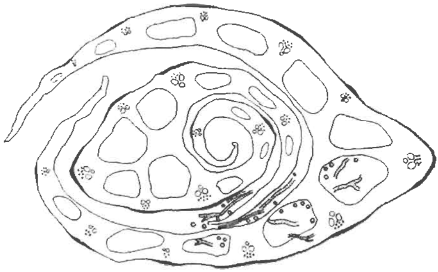
In order to grow the rice plants under sterile conditions the method used by Ward (13) in his investigations on the rust of wheat was employed. The seeds were first sterilised in 1% commercial formaline and then sown in sterile potato tubes containing Knop's solution. It was found that sterilisation was more efficient if performed under the air pump, the liquid, in this way, penetrating the space between the glumes more readily. Owing to the laboratory temperature in February being rather low for the growth of rice, the tubes were kept in an incubator at a temperature of 30° C. The incubator was left with its glass door facing a large north window, and, for several hours in the middle of the day, the tubes were removed and placed in the sun

The young plants were infected when they were about 7—10 days old and about 3—4 inches high. The first series of infections was made with small black sclerotia from an agar culture about one month old. None of these inoculations gave any result, the sclerotia failing to germinate. Subsequent trials with sclerotia from old cultures showed that they had, not infrequently, lost the power of germination. Fresh inoculations were then made from a culture three days old, in which the hyphæ were still growing vigorously, and sclerotia were not yet formed. A small speck of agar was removed from such a culture and placed upon a rice culm, about 1 inch above the remnant of the seed : hyphæ quickly spread from this centre over the exterior of the culm, which gradually lost its green colour and turned brown near the seat of infection. As the outer leaf sheath turns brown, the lamina attached to it also loses its green colour and wilts (Pl. I, Figs. 2, 3) ; finally, the process extends to the central leaves, and the whole plant dies. During the progress of the infection a light weft of hyphæ can be seen investing the culm ; in the later stages of the disease small, dense, white aggregations of hyphæ appear in this mycelium, and, ultimately, become hard black sclerotia of the usual type. This superficial production of sclerotia is a characteristic of the section Libera of this genus. We have, however, seen that sclerotia may arise in the more deep-seated portions

of the host (Pl. III, Fig 1), so too much stress must not be laid *on this character*. The first sclerotia usually occur about the top of the first leaf sheath, either on its inner or outer surface; in the former case they appear as small dark swellings beneath the dry and withered leaf base. The time taken from the first infection until the death of the plant and the production of the sclerotia is about two weeks.

Portions of dead and dying plants, some of which had not yet produced sclerotia, were incubated in agar tubes. In all cases they gave cultures of *Sclerotium Oryzæ*, which exactly resembled those from which the inoculations had been made. Since the infections showed that the fungus was strongly parasitic, and could penetrate the uninjured external surface of the plant, it was not considered necessary to make wound inoculations. On the whole, 70—80% of the inoculations proved fatal.

Microscopic examination showed that the behaviour of the mycelium in the infected culm was not without interest. The



bulk of the hyphæ appear to run longitudinally in the large air cavities of the leaf and in the cells bordering on them (Pl. II, Fig. 11), while a certain number grow outside the leaves in the spaces between the folds of the lamina; these latter are particularly obvious investing the delicate edges of the inner leaf (see text figure). It is at spots such as this that the rice plant is

peculiarly liable to infection by the fungus. On the outer, dorsal, surface of the leaf sheath the epidermal cell walls are much thinner in the areas between the vascular bundles than they are immediately behind them, and, at the edges of the leaf, they are extremely delicate. Moreover, immediately behind the vascular bundles, not only the epidermal, but two or more hypodermal layers have thickened walls, which give a cellulose reaction with chlorzinc iodide (see text figure). On the ventral surface of the leaf sheath the epidermis is uniformly thin, and does not show any such differentiation. Thus, on the outer surface of the leaf sheath, there are areas which offer a poor resistance to any parasitic attack. Once the fungus has gained an entry at one of these spots, progress to the more delicate and deeper seated tissues is easy.

The hyphæ are both inter-and intra-cellular. It is by no means unusual to find that a hypha which has penetrated a cell wall possesses a pronounced thickening in the portion on that side of the cell wall from which penetration has taken place (Pl. II, Fig. 11). This swelling may be taken as evidence of the increase in chemical activity, probably in the direction of the secretion of enzymes, which precedes the solution and penetration of a cell wall.

A distinction must be noted here, between the behaviour of the infected plants used in the inoculation experiments, and the course of the disease in the field. A successful inoculation killed the infected plant completely (see Pl. I, Fig. 3); but, in the field, the result of an attack seemed rather to be a gradual weakening of the host, culminating in the failure to produce good seed. Further experiments on a field scale are necessary to elucidate this point. It may perhaps be the case that rice plants grown under the sterile conditions of our experiments were less capable of resistance to the disease than under normal circumstances

CONCLUSION.

The above account differs in several important respects from that of Cattaneo. In particular the Italian author describes

some unusual structures in the sclerotium. He states, that *when the sclerotia are about a fortnight old several vacuoles make their appearance in the interior, and, ultimately, coalesce to form one large central space; the sclerotium thus becomes hollow. From the solid exterior hyphæ now grow into the central vacuole and bear spores. The spores are circular structures, about 12μ in diameter, and are either borne terminally, or else laterally, on the walls of the hyphæ. Such a* method of spore formation was never observed in our cultures, nor did a series of microtomed sections reveal a sclerotium as anything but a solid pseudoparenchymatous structure. The only bodies bearing any resemblance to the spores of Cattaneo were the oil drops in the hyphæ. By crushing a sclerotium the hyphæ become torn and the oil drops set free. Under these circumstances the oil drops may adhere to the sides and ends of hyphæ, in positions not unlike those which Cattaneo figures for the spores.

No trace of a perfect stage was ever observed. Brefeld (1) has pointed out that the sclerotia of certain *Basidiomycetes* (*Agaricus*, *Coprinus*, *Typhula*), and of *Penicillium* and *Erysiphe*, arise by the interlacing of branches of a single hypha, while those of the genus *Peziza* are formed rather from a plexus of interwoven filaments. This comparison has been somewhat erroneously generalised by some writers (Stout 10) into the statement that the sclerotia of *Basidiomycetes* arise from a single hypha and those of *Ascomycetes* from a plexus of hyphæ. In the genus *Rhizoctonia* it has been found (Shaw 8) that *Rhizoctonia Solani*, Kühn, forms its sclerotia from a single hypha, whereas, in the macro-sclerotial species, of which *Corticium vagum* is the perfect stage, the sclerotia arise from a mycelial plexus. It is evident, therefore, that this character does not afford any basis for taxonomic consideration, since both methods of sclerotial formation occur in both *Basidiomycetes* and *Ascomycetes*.

It is interesting to note the changes in the appearance of the fungus, according to the nature of the nutrient substratum. These changes are most marked in the colour and form of the

hyphæ, and, as Stevens and Hall (9) have already pointed out, afford ground for reflection when we consider the characteristics on which some groups of the *Fungi imperfecti* are classified.

Against a parasite such as *Scl. Oryzæ* it is difficult to see what remedial measures can be employed with success. The sclerotia of the fungus undoubtedly perennate in the soil, where, under favourable conditions, they germinate and produce a mycelium which attacks the paddy crop. Cattaneo suggests the application of salammoniac, with a view to killing the sclerotia in the soil. Even if this is successful on a small scale, it is manifestly impossible to the extent which would be necessary in India. Probably the breeding of resistant varieties is the only method by which any permanent resistance could be made in the case of a field crop such as rice. Fortunately the damage done in India at present does not appear to be sufficient to bring this question within practical consideration.

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APPENDIX.

GLUCOSE AGAR.—

Extract of Lemco	4 *grms.*
Sodium chloride	5 ,,
Peptone	10 ,,
Glucose	20 ,,
Agar	15 ,,
Water	1000 c.c.

RICE AGAR.—

Take 50 grms. of crushed rice seed and boil with 300 c.c. of water for 1 hour, strain through a wire gauze. Dissolve 10 grms. agar in 200 c.c. water, add the decoction and heat to mix thoroughly.

Oat Agar, Lima bean agar and French bean agar are prepared in the same way with the substitution of oats, Lima bean, or French bean for the rice grains.

FILTER PAPER.—

Ammonium nitrate	10 grms
Magnesium sulphate	1 ,,
Potassium phosphate	5 ,,
Lactic acid	2 ,,
Water	1000 c.c.

Take 50 c.c. of above solution, add 10 grms. filter paper and sterilise.

DESCRIPTION OF PLATES.

PLATE I.

FIG. 1.—Rice plant infected with *Sclerotium Oryzæ*—note the young shoots growing out from the base of the infected culm and the outer sheathing leaf covered with sclerotia × 1.

FIGS. 2, 3.—Young plants inoculated with *Sclerotium Oryzæ*. In 3 sclerotia are forming. × $\frac{2}{3}$.

FIG. 4.—Culture on Lima bean agar. × 1.

PLATE II.

FIG. 1.—Rice plant with *Sclerotium Oryzæ*—note sclerotia formed within hollow stem. × $\frac{4}{5}$.

FIGS. 2, 3, 4.—Young and old sclerotia from glucose agar culture. × 50.

FIG. 5.—Hypha from the edge of glucose agar culture. × 700.

FIG. 6.—Appendage on hypha. × 700

FIGS. 7, 8.—Appendages borne in peltate fashion. × 700.

FIG. 9.—Chlamydospores from rice agar culture. × 700.

FIG. 10.—Hypha from rice agar culture breaking up into chlamydospores and single cells. × 700.

FIG. 11.—Longitudinal section of leaf showing hyphæ in intercellular space and cells bordering on it. × 700.

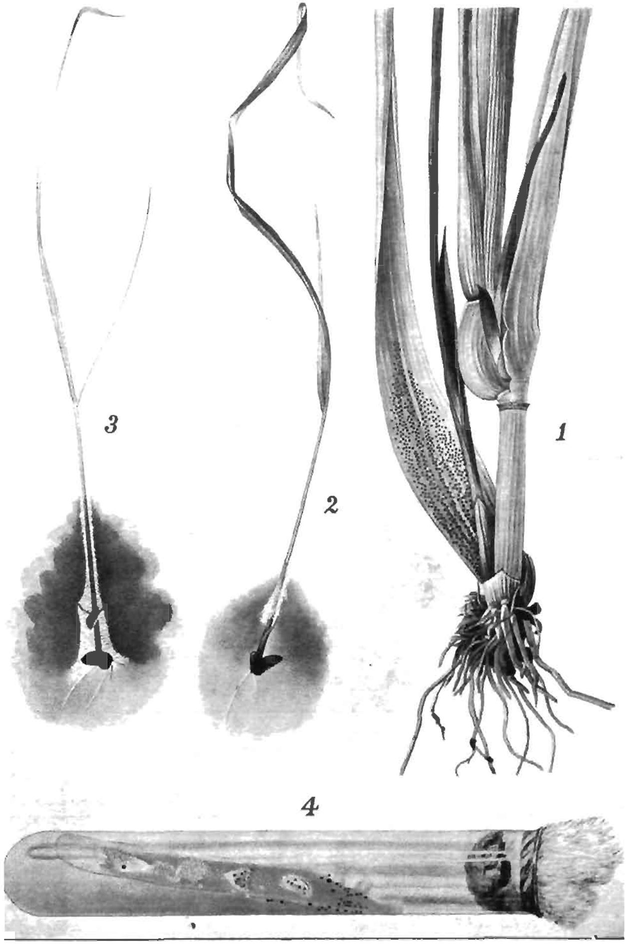
PLATE III.

FIG. 1.—Microphotograph. Transverse section of stem of diseased rice plant from Pusa crop. Note two sclerotia present on the inner surface of stem and one small sclerotia in large air cavity. × 50.

FIG. 2.—Microphotograph. The same showing hyphæ in cells. The rounded bodies with dark centres are starch grains. × 170.

FIG. 3.—Microphotograph. Section through mature sclerotium. × 130.

PLATE 1.



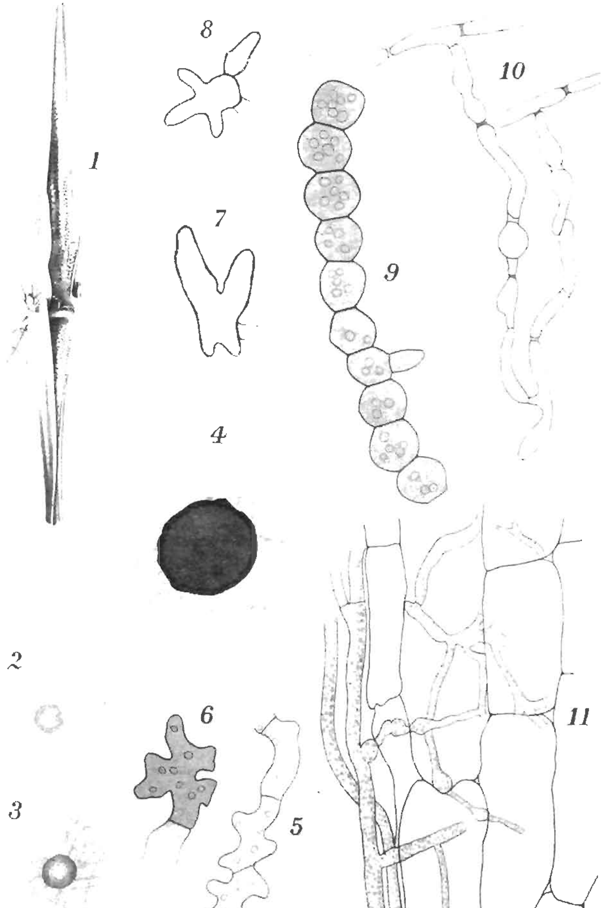

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PLATE III.

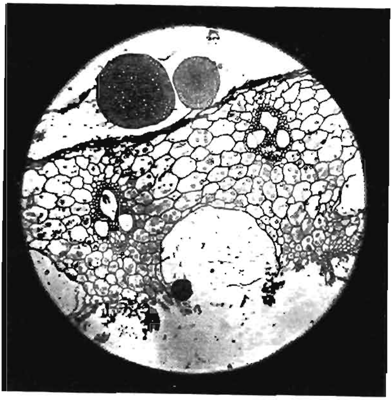

Fig. 1

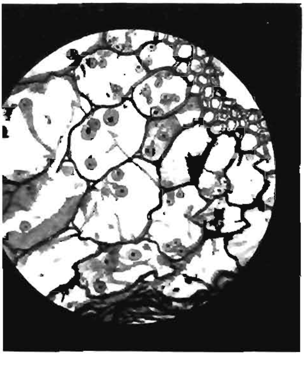

Fig. 2.

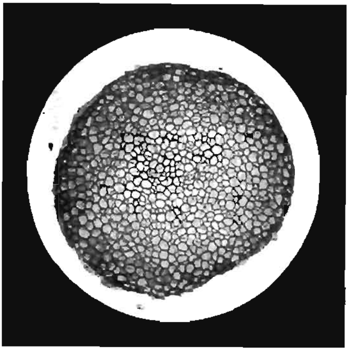

Fig. 3.

STUDIES IN INDIAN TOBACCOS.

No. 3. THE INHERITANCE OF CHARACTERS IN NICOTIANA TABACUM. L.

BY

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I. INTRODUCTION.

THE chief direction in which the tobaccos of North-East India can be improved is in the introduction of superior quality. Many of the varieties at present grown give large yields and are, in consequence, very profitable, but the cured leaf produced from them is, as a rule, of very poor quality and is coarse, deficient in texture, flavour and aroma. For this reason it can be used for Indian consumption only, and, consequently, fetches a very low price. Improvements in the quality of tobacco may be obtained in three ways: (1) by the discovery of new methods of cultivation by which healthy growth is promoted and a larger yield and a better quality of leaf produced; (2) by the introduction of improved methods of curing; and (3) by the growth of superior kinds. Some of the work done at Pusa on the cultivation of tobacco has already been published.[1, 2] The investigations on curing are still in progress and it is hoped to publish shortly the results obtained. The present paper deals entirely with the third aspect of the question and is a

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[1] Howard & Howard, *Memoirs of the Department of Agriculture in India*, Bot. Ser. Vol. III, No. 1, 1910.

[2] Howard, *Agricultural Journal of India*, Vol. III, 1912.

continuation of the work already published as "Studies in Indian Tobaccos, No. 2, The Types of *Nicotiana tabacum*, L.[3]" In that paper an account was given of the work done with regard to the study of varietal characters and the isolation of pure forms. The stability of the type was discussed and it was shown that there is no foundation for the belief, often expressed, that the uniformity of type in any particular kind is easily disturbed by its introduction into a new locality. If cross-pollination be prevented, varieties or types of *N. tabacum* remain as constant as those of other species of plants. This result has recently been confirmed in America by Hasselbring.[4] The methods of pollination were also studied and fifty-one pure types were isolated. These types have since been maintained in pure culture in the Botanical Area at Pusa and have bred true to type from year to year. They form the material with which the investigations, now to be described, have been carried out.

With regard to the improvement of the variety, the immediate problem at Pusa is the production of a good cigarette tobacco. The chief requirements in a cigarette tobacco for growth in Bihar are :—

1. General robustness and rapidity of growth, both in the seedling and later stages of the plant.

2. A plant of medium height with many leaves and short internodes.

3. Fairly broad leaves with small veins, so that the cigarette paper may not be damaged in the process of manufacture.

4. Yellow colour in the cured leaf.

5. Good texture in the cured product.

6. Good flavour.

The characters in which the local tobaccos are most deficient are those of texture and flavour. Several kinds have been found possessing a fair colour.

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[3] Howard & Howard, *Memoirs of the Department of Agriculture in India* (Bot. Ser., Vol. III, No. 2, 1910.

[4] Hasselbring, *Botanical Gazette*, Vol. LIII, No. 2, 1912.

Many attempts have been made in the past to introduce into India the best varieties of cigarette tobacco from America, but the results have been disappointing. This is due to several causes, some of which are avoidable. In the first case, insufficient care was taken to prevent cross-pollination, and the introduced varieties, by crossing with the indigenous crop, deteriorated. In the second place, many of the varieties were unsuited to Indian conditions by their habit of growth. The practice in America of topping at a high level has favoured the growth of tall kinds, which carry their best leaves well above the ground, making low or medium topping impossible. This is a serious disadvantage in the plains of India, where high winds frequently occur and damage tall varieties or those with thin leaves. Another defect was noticed in all the American varieties tried at Pusa, namely, the slow growth of the seedlings. Although sown at the same time as the indigenous varieties, transplanting could only be carried out a fortnight or ten days later in the case of the American kinds, and there was a corresponding lag all through the growth period. This is a very great disadvantage in Bihar, where one of the secrets of success in tobacco-growing lies in the maximum utilization of the growth period from October to mid December. During this period, the temperature is still high enough for rapid growth to take place and the soil still contains plenty of moisture. After the middle of December, when the temperature falls, growth is much less rapid, and the plant should then be nearing maturity and be ready to be cured about the end of January, in order to avoid the dry hot winds which do so much damage during the latter process. *A crop, which through lack of food materials or* through the lateness of the variety makes little growth during October and November, remains more or less stationery during December and January and begins to grow again as the temperature rises in February. Such plants seldom attain any great size, and very frequently do not ripen evenly. The difficulty in curing the product during the period of the hot west winds is

an additional disadvantage. Owing to lateness and want of robustness, the yield of the American varieties is far below that of the coarse local kinds and this would be fatal to their successful introduction.

The chances of improving the quality of Indian tobacco by the introduction of a new variety from America are therefore not great. It will be necessary to build up, by hybridization, new kinds of tobacco, suited to Indian conditions of growth, which possess in addition the qualities necessary to obtain a better price. Fortunately, the introduced American kinds, although they lose their colour by the native method of curing, nevertheless maintain their good texture and flavour, the chief points in which the Indian tobaccos are deficient. Thus by combining these desirable qualities with those of an indigenous tobacco, which is robust and possesses a suitable habit of growth, a very great improvement might be effected. Unfortunately, however, although tobacco is grown over so large a portion of the world, very little work has been done on the hybridization of this crop and little is known as to the inheritance of the various characters which are of economic importance. As in hybridization lies the greatest chance of producing a permanent improvement in the tobacco grown in the plains, and as it is possible to obtain at Pusa all the facilities necessary for such an enquiry, it was decided to take up the question and to make a thorough investigation of inheritance in this crop, beginning with those morphological characters which are of economic importance, namely, those concerning the habit of the plant and the leaf. The subject has proved to be far more complicated than was at first supposed, and the present paper must be considered to be a preliminary one only. It will probably take some years to obtain a complete knowledge of the subject.

Besides its economic importance, there is another point of great interest involved in the genetics of *N. tabacum*. Most of the characters are concerned with the size of organs, and the

inheritance of these can only be determined by quantitative means. The importance of a thorough study of the inheritance of characters, which can be accurately measured, instead of depending on observation alone, has been pointed out by many writers.[1,2] Until recently, most of the investigations on inheritance, undertaken from the Mendelian standpoint, have dealt with characters of a qualitative nature, that is, they have dealt with characters which depend on the presence or absence of a particular attribute, such as colour, hairs or awns. Forms in which these attributes are absent occur and can be used as analysers, and the observations are restricted to a detection of the presence of the character involved. By a judicious use of the analysers and a careful analysis of the progeny, it is generally possible by observation alone to determine the principles underlying the inheritance. Characters connected with the size of organs present more difficulty. In the first place, no absence of the character is possible and no analysers exist. Take, for instance, the height of a plant or the length of a leaf, a plant without height or a leaf without length is inconceivable. Thus in such characters we are dealing with difference in degree only; observation is insufficient and measurement must be employed. In the second place, such characters are generally very sensitive to changes in environment and show marked fluctuating variability. Such fluctuating variability may be inherent in the plant, or may be directly due to the influence of the environment on the character under consideration, or indirectly to the effect of the environment on the general vigour of the plant. Should the changes due to fluctuating variability be greater or almost as great as the differences in the characters under investigation, they may obscure or entirely mask the effects of inheritance. East[3] was one of the first to point out that so-called

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[1] Tammes, *Recueil des Travaux Botaniques Néerlandais*, Vol. VIII, 1912.

[2] Nilsson-Ehle, *Kreuzungsuntersuchungen an Hafer und Weizen*, Lund, 1909, *Kreuzungsuntersuchungen* II, Lund, 1911.

[3] East, *The American Naturalist*, Vol. XLIV, 1910

continuous variation was capable of a Mendelian interpretation. The whole subject of the inheritance of characters with fluctuating variability has been very ably dealt with recently by both Tammes[1] and Nilsson-Ehle.[2] The latter was the first to show that characters, which to the eye appear similar, may in reality be due to different genes which are inherited independently. The red colour of the pericarp of some wheats is composed of three factors, each of which will independently produce a red colour, although less intense in tone than that due to the combination. Recent work everywhere endorses the complicated nature of most characters and has resulted in a large increase in the number of factors recognised, while at the same time the visible effect due to each factor appears smaller. In the paper quoted above, Nilsson-Ehle discusses fully the question of fluctuating variability and variation in general, and points out that fluctuating variability may only exist as an effect of environmental influence. If the number of factors n is large, the number of homozygotic combinations possible will be much larger, *i.e.*, 2^n and the differences between these combinations will be smaller than the differences between the factors themselves. If the heterozygotic forms are intermediate in value between the homozygotic combinations, we may obtain a continuous series in the F_2 generation and as the combinations of middle values occur most frequently, the form of the curve, obtained in a graphic representation of the F_2 generation, will resemble that of an ordinary frequency curve. The heterozygotic combinations, which occur at different points on this curve, will in the F_3 and succeeding generations give a progeny which varies within much smaller limits than those of the F_2. Assuming a large number of small factors, this is sufficient to explain all variation which is not induced by environment. A plant which exhibits small fluctuations in any one character may be heterozygotic as regards that character and it should be

[1] Tammes, *l.c.*

[2] Nilsson-Ehle, *l.c.*

theoretically possible to extract different types which breed true from it. In practice, however, errors of measurement and observation or environmental influence may be too great for such types and their heterozygotes to be distinguished. From these considerations as well as the experimental evidence of his own researches, Nilsson-Ehle concludes that there is no inherent difference in the mode of inheritance between quantitative and qualitative characters and that all variations may be placed in two groups :—

1. Variations which are inherited.

2. Variations which are not inherited and which are probably entirely due to changes in the environment.

It is obvious that the larger the number of factors in which the parents differ and the greater the effect of environment, the more difficult it becomes to separate the factors or to determine the exact mode of inheritance. If we consider the case of two parents, which differ from one another in three factors, there will be in the F_2 generation eight homozygotic combinations and nineteen heterozygotic, which, in general, will lie between the homozygotic forms. Thus we obtain a series containing twenty-seven stages between the two parent forms. If the original difference between the parents is not very large, these forms will lie very close to one another. If, in addition, environmental differences supervene, the limits of variation of one form will very soon overlap those of the next or even of several others, in fact, in many cases, the limits of the two parents themselves overlap.

Taking these facts into consideration, it is not surprising that up to the present in no case has the inheritance of the size of an organ been entirely elucidated and the various factors determined. All that has been possible has been to show that segregation undoubtedly occurs and that the facts are in accordance with the Mendelian interpretation and with the existence of many factors, all capable of being inherited independently. In the investigations described in this paper it has been possible

not only to show segregation in many of the characters, but also to isolate forms resembling the parents as well as some new constant forms differing from either parent.

The most thorough examination of the inheritance of characters connected with the size of organs are the investigations of Tammes[1] on the length and breadth of the seed and the length and breadth of the petal in *Linum*. The size of the seed was found to be practically unaffected by the environment and therefore formed very suitable material for such work. The limits of variation and the co-efficient of variability were carefully determined for each parent. It was found that while the F_1 generation was intermediate between the parents, the second generation could not be separated into groups, but formed a continuous series, and that, in many cases, no individuals could be found which resembled the parents. In the F_3 generation no individuals breeding true or resembling either parent could be found but the limits of variation were smaller than in the F_2 and differed in each case, the combined variation covering the limit of variation of the F_2 generation. These results point to the existence of several factors with segregation. The various intermediate heterozygotic forms would naturally contain fewer heterozygotes than the F_1 generation, and would therefore vary within smaller limits.

East and Hayes,[2] in 1911, published similar results on size characters in maize, such as height of the plant, length of cobs, weight and size of seeds, but in most cases the investigations were not taken beyond the second generation.

Three investigations on the characters connected with the size of the organs in tobacco have been published, but in no case have the investigations been carried beyond the second generation. Lock,[3] in 1909, published a preliminary note of some species crosses in the genus *Nicotiana*, the characters considered

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[1] Tammes, *l.c.*

[2] East and Hayes, *Bulletin* 167, *Connecticut Agricultural Experiment Station*, 1911.

[3] Lock, *Annals Royal Botanic Gardens, Peradeniya*, Vol. IV, 1909.

being the colour, shape and size of the corolla. As the investigation is complicated by the fact that species crosses were employed with consequent sterility and as it is admittedly only a preliminary account with very few data, it need not be further considered here.

A much more important paper dealing with *N. tabacum* only was published by Hayes[1] in 1912. The correlation and inheritance of various characters such as the height of the plant, number of leaves, average area of the leaves, average width and average length of the leaves, were investigated in hybrids between various pure types of American tobacco. Full details are given of the measurements, but in no case have the cultures been carried beyond the second generation. It was found that the variability in the F_1 generation and the parents was similar but much greater in the F_2 generation. These results are most easily explained by the presence of a large number of small factors with segregation. As regards the correlation between these characters, the co-efficient in all cases was found to be less than +. 5, except in the case of the length and width of the leaf, where a distinct plus correlation was found. The conclusions, as regards the individual characters, will be considered in more detail in the separate sections dealing with each character in Chapter IV, but it may be remarked here that although the results are undoubtedly valuable, many of the measurements are taken in what appears to be a somewhat arbitrary manner. For example, the number of leaves counted is not the total number of leaves borne on the main stem of the plant, but the number of leaves which occur between the fifth leaf from the ground and the last leaf on a topped plant, this representing the total number of leaves generally harvested. Such numbers have an economic but no physiological meaning. Similarly the height is measured to the last leaf counted, not to the end of the main axis of the plant. As the habit of growth of the American types used is very similar, discrepancies due

[1] Hayes, *Bulletin* 171, *Connecticut Agricultural Experiment Station*, 1912.

to this method of measurement are not so great as they would be in the case of many Indian tobaccos (see Plates I and II). Nevertheless these arbitrarily chosen points cannot give the expression of the true physiological activity of the plant as regards height and number of leaves.

A third paper on the inheritance of quantitative characters in *Nicotiana* is that published by Goodspeed.[1] In the first part of these investigations a comparison is made between the weight of the seeds obtained by hybridization and the plants produced from these seeds. *N. tabacum* var. *macrophylla*, a variety with heavy seed, and *N. tabacum* var. *virginica*, a variety with light seed, were employed as parents. The seeds of the F_1 generation were divided into three groups, heavy, light and medium, and it is stated that in the plants raised from the heavy seeds the greater number of individuals resembled var. *macrophylla*, while in the culture raised from the light seeds the greater number resembled var. *virginica*. The three classes of seeds showed a difference in germinating power which was largely influenced by time. The conclusion is therefore drawn that very variable results may be obtained in the F_2 generation which are due merely to the differential germinating power of the various heterozygotic and homozygotic combinations. The experimental data on which these conclusions are based can, however, only be regarded as most unsatisfactory. In the first place, considering the number of characters and the probably infinitely larger number of factors involved in the difference between two *varieties* of tobacco, it would be practically impossible to divide the F_2 generation into three well-defined groups and any such division which might be attempted would have no significance. In the second place the original division of the hybrid seed into three groups is open to question for the same reason. The difference between these seeds probably depends on several factors, and to these must be added environmental effects due to nutrition and pollination. Very little meaning can be attached

[1] Goodspeed, *University of California, Publications in Botany*, Vol. V, No. 2, 1912.

to results in which so many approximations have to be made. In the second part of the paper, an investigation into the inheritance of the length of the corolla in three varieties of *N. acuminata* is described and the author states that, although this character shows very small fluctuations in the parents, the variation in the F_1 is very great and covers the whole difference between the two parents. The details of the F_2 generation have not yet been published.

The only other investigations on hybridization in the genus *Nicotiana*, which are known to me, are those by Jensen[1] and Lodewijks.[2] Hybridization experiments were started by Jensen in 1906 and the crosses investigated in most detail were those between Peru, a variety with a petiolate leaf, and White Burley, Peru and Maryland smoking. The intermediate nature of the F_1 and the great complexity of the F_2 generation, with a total absence of the parent forms was emphasized. The most interesting point is the appearance of new characters in the offspring which were not present in either parent.

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[1] Jensen, *Jaarboek van het Department van Landbouw in Neederlandsh-Indie*, 1907 1908, 1909, 1910, 1911.

[2] Lodewijks, *Zeitschrift für induktive Abstammungs und Vererbungslehre*, Bd. V, 1911.

II. THE METHODS OF RAISING THE EXPERIMENTAL PLANTS.

THE methods employed at Pusa in raising the experimental plants have already been fully described[1] in a previous paper, and it will only be necessary briefly to recapitulate them. In experimental work on tobacco, the two most important points are: (1) to raise the seedlings without contamination, and (2) to eliminate, as far as possible, all differences due to environmental influences.

The seeds of the tobacco are so small that they are very easily carried from one culture to another by wind, rain, earthworms, or by the hands of the workmen. The seed is brown and indistinguishable from the soil, and retains its vitality, even under adverse conditions, for several years. The practice adopted at Pusa is to raise the seedlings in large shallow boxes, and every precaution is taken to collect the earth and leaf-mould from places where contamination by stray tobacco seed is impossible. The boxes are made up about six weeks before sowing and kept moist, so as to cause any stray seeds to germinate. So far (1908 to 1912) no tobacco seedlings have been found in the boxes prior to sowing. The boxes are sown, one at a time, and the sower has to wash his hands before sowing another box. After sowing each box it is immediately removed into the shade till the seedlings appear. They are then enclosed in a wire netting fence to keep off animals, and are placed so far apart that the earth from one box cannot be splashed on to an adjacent one by the sudden tropical storms which sometimes occur at this season. Precautions are taken during the process of thinning to prevent admixture and this operation is only

[1] Howard and Howard, *l.c.*

carried out under personal supervision. The boys who do the work have to wash their hands after finishing each box, as otherwise a few ungerminated seeds might be carried to other cultures. After transplanting, the soil in the boxes is thrown away and the boxes washed. These precautions have proved successful and in no case has any mixture of the cultures been discovered.

The elimination or rather the reduction of the differences due to environmental influence is much more difficult. There is perhaps no plant which is so sensitive to changes in soil, climate and external conditions generally as the tobacco. The shortness of the growth period, the large amount of material in the form of leaves and stem formed in a short time are probably the reasons why any check or stimulus has so great an effect. Moreover, the tobacco plant appears to have an infinite capacity to adapt itself to conditions, the same pure type giving rise to plants 1½ feet or 8 to 10 feet high according to the cultivation. Even in very adverse circumstances the plant goes through its complete cycle and forms seed. Apart from such extremes, a very small difference in cultivation is sufficient to induce a very marked change and to raise a field of plants uniform enough for accurate measurement is not easy. Nevertheless, in all plant-breeding experiments, the absolute necessity of normal and well-grown plants cannot be emphasized too strongly. The differences induced in tobacco plants apart from size are almost incredible. The general effect of unfavourable environment on *N. tabacum* is to wipe out all differences and to make the plants appear uniform. The differences between the various types in leaf shape and leaf surface, which are small, almost disappear in under-developed plants. Unless the plants are well grown, it would be very easy to be misled in observations on such characters as the undulations of the leaf surface. The numbers would probably show far too great a proportion of flat leaves.

Owing to the large amount of experimental work carried on in the Botanical Area at Pusa, special care has been taken to

render the land as uniform as possible. The plots are all small, carefully levelled and are well drained and cultivated, and for most crops they present an ideal experimental basis. In the present investigations, a certain amount of trouble has been experienced even on these experimental plots. Slight local unevenness of the ground due to ploughing, a difference in the subsoil drainage, and the proximity of a hedge have all had an effect. It is needless to say that all cultures which could possibly have been affected have been rejected. The cultures which have to be directly compared are grown on the same plot in lines and the two parent types are grown at both ends of the plot, and also in the centre. In this way, should there be any slight change in the conditions from one side of the plot to the other, it would be indicated by the range in variation of the parent forms. The impossibility of obtaining a large piece of land with uniform drainage and soil must always limit the number of cultures grown, even if the amount of work entailed did not do so. One other important point must be mentioned, namely, the time of transplanting. If many plants die after the first transplanting and have to be reset, the replaced plants, even though only a week later in planting, always remain behind the earlier ones. By adopting a system of furrow irrigation, and using great care in removing the seedlings from the nursery boxes, the loss in transplanting in the experimental cultures has been reduced to a minimum. Only one replacement is carried out two or three days after the first transplanting. Should others die, their places remain blank, but the system of transplanting adopted has proved so successful that the number of such blanks is very small indeed ; the number of deaths before the first replacement is generally not more than one per cent.

The methods of crossing and raising the self-pollinated seed are those in ordinary use, and need not be specially mentioned. Full details have been given in a former paper.[1] The only point

[1] Howard and Howard, *l.c.*

which calls for comment is the limitation imposed on the number of possible observations by the labour connected with the raising of all the seed under bag. Many of the types will not set good seed unless they are selfed, and the time taken in carrying out all the details connected with this and the bagging of a large number of plants is considerable. The raising of the seed and the observations on the leaves have to be carried out during the same period, between the formation of the first flowers and the partial destruction of the leaves by death or the ordinary chances of breakage. This in Bihar is a very short period, and even by devoting the whole day to the work the number of observations which can be carried out in the time falls far short of those desired.

III. THE OCCURRENCE OF PARTHENOGENESIS.

The question of parthenogenesis in *N. tabacum* was taken up in consequence of a paper published in the *Mendel Journal.*[1] In this communication the author stated that she had been able to obtain parthenogenetic seed with the greatest ease in the case of *N. sylvestris, N. tabacum, N. suavolens, N. sandera,* and hybrids from these. In some cases only the anthers were removed, but in others both anthers and stigma, while the ordinary precautions of sterilizing the instruments and enclosing the flowers in wax-paper bags seem to have been scrupulously observed. Success did not attend all the experiments, but "parthenogenesis was discovered in ten species, varieties and hybrids of *Nicotiana* on chosing the right period for trial, *i.e.*, when the plant is beginning to go off its fullest bloom. In the tabacums success was unfailing." East[2] also mentions the possible production of apogamous seed. "In crossing species of the genus *Nicotiana* I have had plants develop from seed that have apparently been formed apogamously, that is, formed from an immature egg-cell without fertilization. It is evident that this is induced by the extraordinary irritation of foreign pollen."

Experiments were undertaken both in 1910 and 1911 to determine whether, under the conditions obtaining in Pusa, *N. tabacum* will set seed without pollination. It had already been observed that castrated flowers prepared for hybridization, which owing to pressure of work or other reasons had not been pollinated, invariably dropped without setting any seed. In order to obtain more definite information on this point, a large

[1] Haig Thomas, *The Mendel Journal*, No. 1, 1909.
[2] East, *The Popular Science Monthly*, 1910.

number of flowers on two individuals in nearly all the fifty-one types of Indian tobaccos, and also in some F_1 hybrids, were castrated. About fifty to one hundred flowers were prepared on each plant under every possible condition. In some the anthers were removed, in others, both anthers and stigma. The plants used included types which self-fertilize with great ease and those which will set hardly any seed unless selfed, as it was thought that the latter would be the most likely to produce parthenogenetic seed. Plants were chosen at all periods of their growth—when in full seed formation, when full of capsules and going off their bloom, and when very nearly over. In most cases the plants were heavily pruned, all capsules, flowers and buds other than the castrated ones being removed (such heavy pruning ordinarily induces rapid seed formation), others were lightly pruned. The same methods were adopted in 1911, but here the number of kinds employed was smaller, only those used as parents in the hybridization experiments were tested again, namely, Types 9, 51, 16, 35, 23 and 38. The castrated flowers were enclosed in parchment bags and these were taken off at frequent intervals in order that any newly-formed buds might be removed. In the earlier experiments the bags were not applied after the corollas had withered, but in the later experiments bags with perforations were placed over some of the branches. A great difference was found between the capsules formed from the castrated flowers and those formed by ordinary pollination. In the latter case the capsule swells quickly and remains firmly attached to the plant. No difficulty is experienced in removing or replacing bags, and the peduncle would have to be broken before the capsule could be removed. This is always the case, whether the flower be self- or cross-pollinated. The capsules of the castrated flowers, on the other hand, although they also became swollen at first and simulated the fertilized ones, were very easily detached from the plant. It was exceedingly difficult to remove the bags, which finally had to be cut away carefully. The capsules thus exposed to the air were

easily blown or knocked off. For this reason half of them were enclosed in large well-perforated bags as a protection. Some of the capsules obtained a fair size, but were not so large as the normal ones. On examination they were, however, found to be quite empty, the ovules not having developed. On only three plants did seed set in all the thousands of flowers which had been castrated, and the total number of capsules was five. In 1910, on a plant of Type 9, about one hundred flowers were castrated and one fully formed capsule was found, the seed of which germinated and produced plants similar to Type 9. In 1911, again, on a plant of Type 9. one capsule containing seed was found in about one hundred castrated flowers. In this type the stamens are so much shorter than the style, that if enclosed in a bag the flowers normally set no seed and the majority of the capsules drop. It has always been found necessary to self this type in order to obtain sufficient pure seed to maintain the culture. If the seeds in these two capsules were due to apogamy, this method of seed production must be the exception and not the rule. It is of course possible that the two capsules were due to errors in castration. The other three capsules were found on one plant of another type, but by an accident these were not examined. They were large, well-formed capsules, apparently containing seed, but unfortunately were destroyed before this fact had been definitely ascertained.

Considering the great number of flowers examined and the fact that every stimulus to apogamous seed formation had been given to the plants by pruning and capsule removal, the results obtained are exceedingly small, even if we assume that all five capsules contained parthenogenetically formed seed.

In addition, in all the first generations (nine in number) which have been raised at Pusa during the last five years, each culture containing about one hundred plants, no individuals resembling the mother plant have been detected. The cultures have been absolutely uniform and the reciprocals identical. I

have no hesitation in saying that under the conditions obtaining at Pusa in ordinary hybridization work, parthenogenesis in *N. tabacum* is negligible.

It is interesting to note that in the details given by Jensen[1] of an experiment undertaken to test the possibility of wind pollination in *N. tabacum*, no mention is made of the formation of apogamous seed. Four plants bearing 119 castrated flowers were covered by a net and so placed that the prevailing wind must bring pollen to them. In none of the flowers did any seed set. The uniformity of the F_1 generation and the identity of the reciprocals has also been mentioned by Jensen and by Hayes.[2]

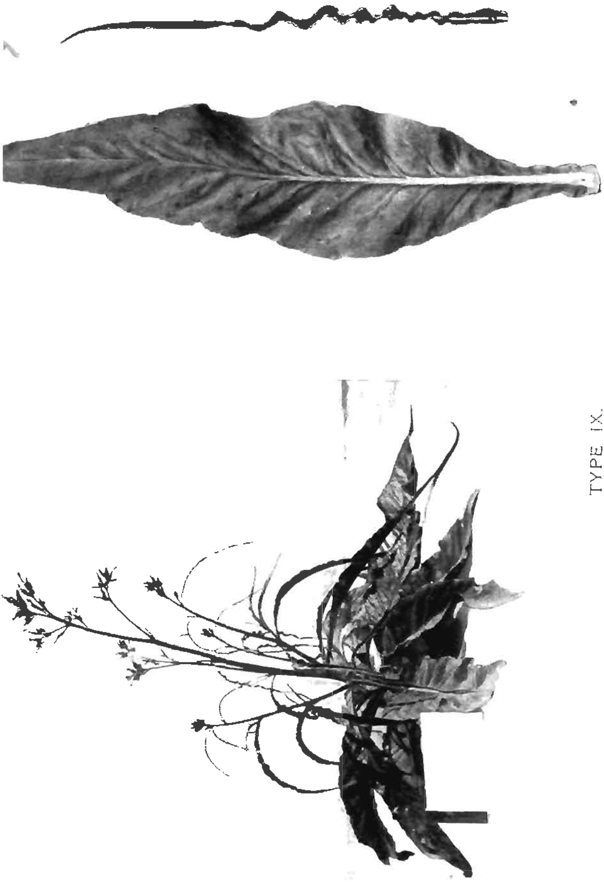
[1] Jensen, *l.c.*
[2] Hayes, *l.c.*

IV. THE EXPERIMENTAL RESULTS.

THE material used in these investigations formed part of the types, isolated in 1909, which have since been maintained in pure culture. Since at the time these experiments were begun nothing was known concerning the correlation or interdependence of the various characters in tobacco, it was decided to make a preliminary survey of the inheritance of practically all the characters which deal with the stem and leaves. This was done partly with the object of ascertaining how far the inheritance of the individual characters could be studied independently, and partly to determine the most suitable methods of investigation. It is hoped to follow this preliminary account by a more comprehensive study of the more important characters. The characters which have been considered in the present investigation are (1) time of flowering, (2) height of stem, (3) arrangement of the leaves on the stem, (4) length of the decurrent portion of the lamina, (5) venation of the leaf, (6) leaf-shape, (7) undulation of the surface and margin of the leaf.

In all, five crosses have been made, Type 9 × Type 51, Type 16 × Type 35, Type 23 × Type 38, Type 2 × Type 3, and Type 2 × Type 51. The first, that between Type 9 and Type 51, has been carried to the F_4 generation, those between Type 16 and Type 35 and Type 23 and Type 38 to the F_3 generation. Only the F_1 generation has so far been raised of the other two. It will be seen from the photographs of Type 9 and Type 51 (Plates I and II), and from the full description of the types reprinted as an appendix to this paper (p. 108), that these two forms differ in almost every character, from height of plant to the mode of pollination and colour of the corolla.

PLATE I.



TYPE IX.

PLATE I

TYPE II

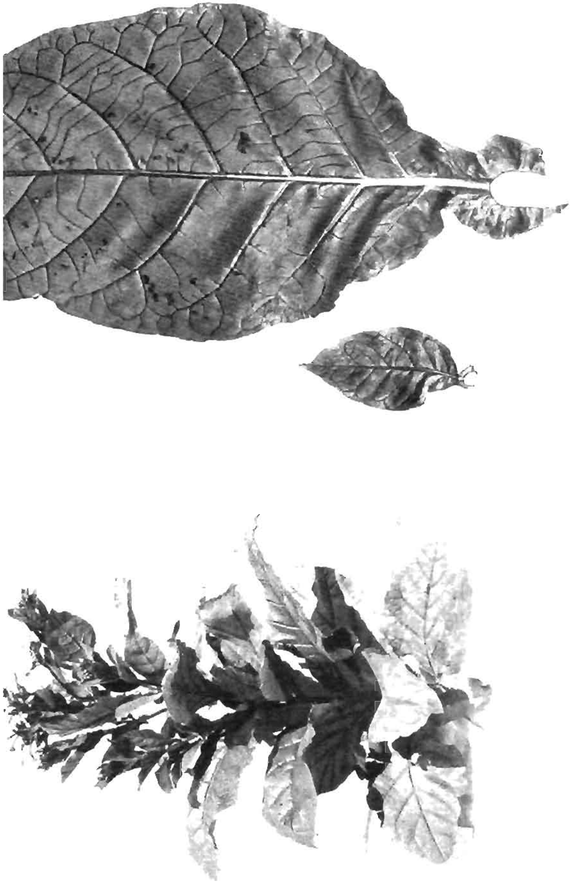
PLATE

PLATE

TYPE XXIII

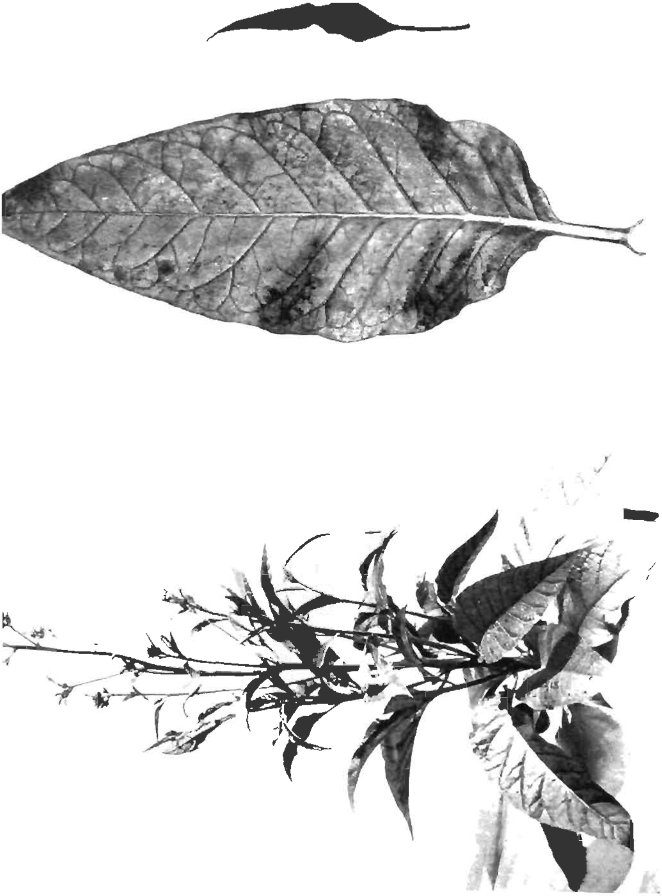
PLATE

PLATE VI.



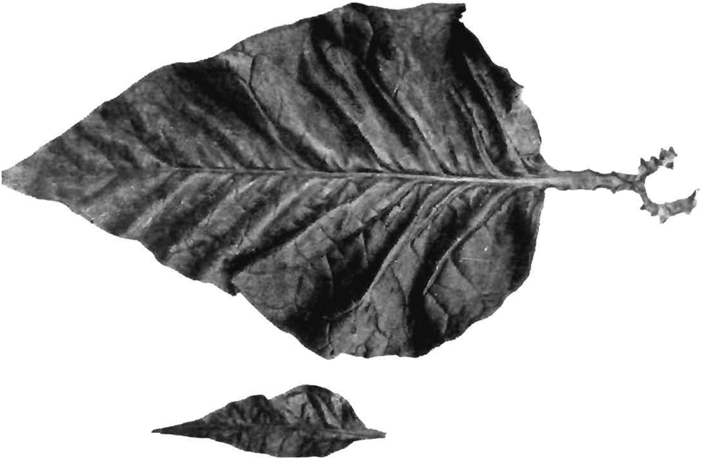
TYPE XXXVIII.

PLATE VII.



TYPE II.

PLATE



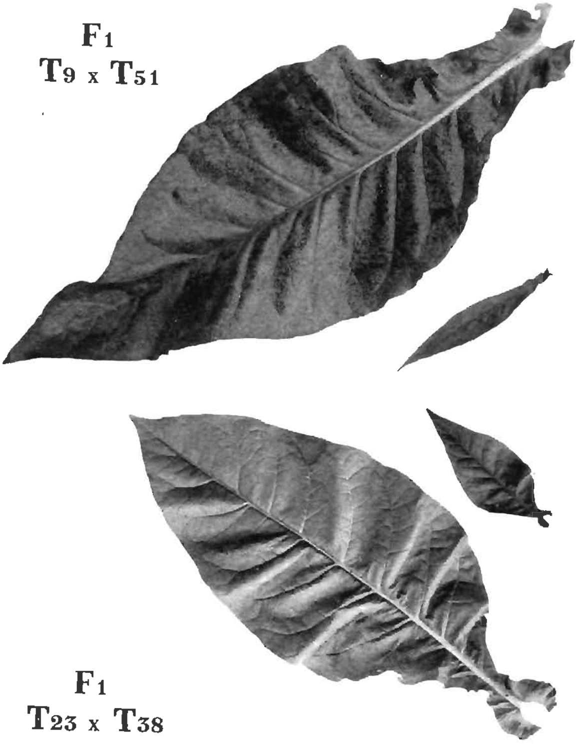
F_1 $T_{23} \times T_{38}$

F_1 $T_{[illegible]} \times T_{[illegible]}$.

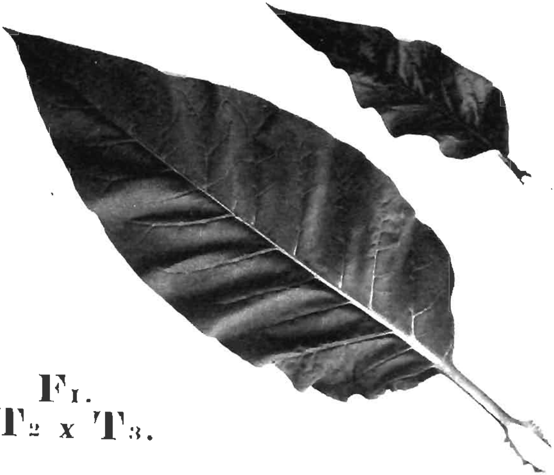
F_1 $T_{[illegible]} \times T_{[illegible]}$.

FIRST GENERATION OF CROSSES IN N. TABACUM.

PLAT



FIRST GENERATION IN N. TABACUM.



F_1.

T_2 x T_3.

F_1

T_{16} x T_{35} .

FIRST GENERATION IN N. TABACUM.

FIRST GENERATION. TYPE 2 × TYPE 51.

In Type 16 and Type 35 (Plates III and IV) we have two forms which, while not very different in height or habit, nevertheless differ markedly in the number of leaves. The main object of the cross between these two forms was an investigation of the leaf shape. Type 35 has the broadest and Type 16 one of the narrowest leaves in all the fifty-one types, while the length is nearly the same in both. The cross between Type 23 and Type 38 (Plates V and VI) was primarily made on account of the difference in the number of leaves on plants almost equal in height. The average number of leaves in Type 23 is nineteen or twenty, in Type 38 about thirty-five. Types 2 and 3 (Plates VII and VIII) are both petiolate forms, but the petioles are alate to a varying degree. In the cross Type 2 × Type 51 (Plates VII and II) a form with a petiolate leaf was crossed with a leaf with a broad base. The most striking result of these hybridizations was the formation of new forms quite outside the range of either parent. For instance, in the F_2 generation of Type 16 × Type 35, dwarf plants, much shorter than Type 35, and tall forms, almost equal in height to Type 16 and Type 35 combined, were found, and some of these have bred true in the F_3 generation. Similarly, in the cross Type 23 × Type 38, petiolate forms breeding true were produced, although both parents have sessile leaves. Reciprocal crosses were always made and grown side by side both in the F_1 and F_2 generations. In no case could any differences between the crosses and the reciprocals be detected. The F_1 was intermediate between the parents in almost all the characters (Plates IX, X, XI, XII).

Details regarding the manner in which the actual measurements were taken will be given in the section on the individual characters, but a few words of explanation may be given here on the number of plants used in the experiments. As explained in a previous chapter (p. 38), the area of uniform land available, the labour involved in the raising of the seedlings and the transplanting, but more especially the shortness of the period during which measurements can be made, limits the amount

which can be accomplished. The descriptions of the various types of tobacco already published show that the different forms of *N. tabacum* can be arranged as regards each character in a series, each member differing very slightly from the next (see also Tables VII, XII, XX). This would lead one to expect a large number of factors in connection with each character, and in the F_2 generation a long series of intermediates, with the very rare occurrence of the parent forms. The chances of directly analysing such an F_2 generation are small. A very large number of individuals would have to be raised in the F_2 generation to obtain any indication of the percentage of plants resembling the parents, and, since the range of variation in the parents due to external influences is considerable, it would be quite impossible to recognise such forms with certainty. This being the case, there seems very little point in undertaking the labour of raising many thousands of plants in the F_2 generation. The plan adopted has been to grow not less than 1,000 plants in the F_2 generation in order to obtain a fair idea of the extent of variation by eye, and then measure as many as possible of these, generally 300 to 600. Self-pollinated seed from plants, which together cover more or less completely the range of variation, was taken and these cultures raised in the F_3 generation. In the F_3 cultures about 200 plants were grown from each parent, and 100 to 200 measured. No choice was exercised in connection with the plants measured. Two or three complete lines of the culture were taken. The limits of variation in the F_3 generation are much smaller. In some cases the cultures apparently bred true in some one character. A similar procedure was adopted in the F_4 generation.

The number of plants used is small and the investigation cannot pretend to be statistic, but the larger the number of plants the smaller must be the number of cultures. The number employed is sufficient to determine whether the culture is uniform or is splitting within narrow limits. The object in adopting this procedure is to obtain as many as possible

of the intermediate forms pure, as the extraction of the various intermediate homozygotic forms appears to be the easiest and most conclusive way of determining the principles underlying the inheritance. The range of variation of the parents was determined each year for each character. In 1911, very few of the parent plants were sufficiently well developed to be measured. The cultures were transplanted into a field which had been green-manured. Owing to the exceptionally heavy and prolonged monsoon of that year, the soil conditions were not favourable to the proper utilization of the green manure, and the plants only developed well in the high-lying portions of the field. The F_2 generation of Type 9 × Type 51 and the crosses of this back on to the parents were normally developed, but most of the parent cultures and the F_1 generation of the other four crosses were very uneven. This explains why the measurements given for the F_1 generation are of a later date than those of the F_2. In all these cases the crosses had to be re-made and the work repeated. Similarly, in 1913, as there were a large number of cultures to be grown, some of the lines of the parents were pushed as near the hedge as appeared safe. Unfortunately, the influence of the hedge had been under-estimated, and although the last line was twenty feet from the hedge, the plants developed very slowly, and were so stunted that they had to be rejected. These accidents make the number of measurements carried out on the parents smaller than is desirable.

I. TIME OF FLOWERING.

The date of opening of the first flower on each plant was taken as the criterion of this character. All the plants were numbered and the cultures were examined daily at approximately the same time in the morning. The climate of India is very well adapted for all such investigations, as the days are almost invariably sunny, and irregularities due to the periods of cloud and low temperature consequently negligible. The results for the three crosses, Type 9 × Type 51, Type 16 × Type 35 and

Type 23 × Type 38, are given in Tables I, II, III. In order to shorten the tables the data are given in three-day periods. The date of flowering of the parents under the same conditions was determined each year.

The most interesting results are those for the cross, Type 9 × Type 51. The parents vary greatly in time of flowering. The flowering period of the first generation is intermediate between the two, but nearer that of Type 9, the earlier parent. The F_2 generation shows a wide range, but the flowering periods of the parents is unfortunately not available for this year, 1911. It may, however, be noted that the flowering period of the F_2 covered two months, a period greater than that covered by both

Date of Flov

	Date of Flowering of Parent.	January.							
		4-6	7-9	10-12	13-15	16-18	19-21	22-24	25-27
ype 9 × Type 51 (1911)		—	—	—	—	—	1	1	1
	1911								
9 (1912)		—	5	11	22	27	23	6	1
51 (1912)		—	—	—	—	—	14	30	25
ype 9 × Type 51 (1912)		—	—	2	11	26	21	14	3
ype 9 × Type 51 (1912)									
737	Feb. 8th	—	—	—	3	16	32	34	15
738	Feb. 8th	1	12	11	26	25	31	26	8
736	Feb. 10th	1	—	1	5	10	24	35	19
740	Feb. 13th	—	—	—	—	—	25	54	20
132	Feb. 13th	—	—	—	—	—	7	28	32
694	Feb. 15th	—	—	—	—	—	5	14	12
167	Feb. 16th	—	1	—	2	2	11	24	14
	1912								
9 (1913)		—	—	—	—	—	7	13	8
51 (1913)		—	—	—	—	—	—	—	—
ype 9 × Type 51 (1913)									
738—15	Jan. 8th	—	—	—	1	6	12	19	32
738—19	Jan. 11th	—	—	—	5	19	36	39	38
738—81	Jan. 15th	—	—	1	6	34	57	50	19
738—58	Jan. 16th	—	—	—	—	—	7	29	23
738—96	Jan. 24th	—	—	—	—	1	—	10	10
738—76	Feb. 2nd	—	—	—	—	—	—	2	5
694—1	Jan. 25th	—	—	—	—	—	—	—	7
694—103	Jan. 30th	—	—	—	—	—	—	—	—
694—10	Feb. 3rd	—	—	—	—	—	—	—	—
694—23	Feb. 4th	—	—	—	—	—	—	—	—
694—38		—	—	—	—	—	—	—	—

parents either in 1912 or 1913. Seven cultures were grown in the F_3 generation and here a distinct difference can be seen in the limits of variation of the individual cultures. Three, namely 738, 736 and 167, have a period equal in length to both parents combined, while 740, 132 and 694 more or less resemble Type 51. Cultures representative of each of these groups, namely 738 and 694, were chosen for future experiment, and six plants of the former and five of the latter were grown in the F_4. It will be seen that the cultures grown from 738 have again segregated. Two, 738-15 and 738-96, cover approximately the period of the two parents. One, 738-81, is distinctly earlier than the early parent, and the others vary over different ranges. The culture 694 has, on the

[T]ype 51.

February.							March.						To No Pla
9-11	12-14	15-17	18-20	21-23	24-26	27-1M.	2-4	5-7	8-10	11-13	14-16	17-19	
76	74	132	86	64	50	33	15	17	12	1	4	2	6[illegible]
—	—	—	—	—	—	—	—	—	—	—	—	—	
1	—	—	—	—	—	—	—	—	—	—	—	—	
—	—	—	—	—	—	—	—	—	—	—	—	—	
—	—	—	—	—	—	—	—	—	—	—	—	—	1[illegible]
1	—	—	—	—	—	—	—	—	—	—	—	—	1[illegible]
—	—	—	—	—	—	—	—	—	—	—	—	—	1[illegible]
—	1	1	—	—	—	—	—	—	—	—	—	—	1[illegible]
2	—	—	—	—	—	—	—	—	—	—	—	—	1[illegible]
4	3	1	—	—	—	—	—	—	—	—	—	—	1[illegible]
3	4	1	—	—	—	—	—	—	—	—	—	—	1[illegible]
—	—	—	—	—	—	—	—	—	—	—	—	—	
5	9	3	3	1	1	3	—	1	—	—	—	—	
12	2	1	3	—	—	—	—	—	—	—	—	—	1[illegible]
—	—	—	—	—	—	—	—	—	—	—	—	—	1[illegible]
—	—	—	—	—	—	—	—	—	—	—	—	—	1[illegible]
11	5	2	—	—	—	—	—	—	—	—	—	—	1[illegible]
26	23	7	7	6	1	2	—	—	—	—	—	—	1[illegible]
24	19	8	7	5	2	—	—	—	—	—	—	—	1[illegible]
17	13	7	3	—	2	1	—	—	—	—	—	—	1[illegible]
10	18	12	18	18	20	9	18	5	2	—	—	—	1[illegible]
16	15	19	20	30	31	12	11	4	4	—	—	—	1[illegible]
1	17	18	24	33	33	21	24	14	4	4	—	1	1[illegible]
3	12	10	11	21	20	28	22	21	11	6	2	—	1[illegible]

	Date of Flowering of Parent.	January.						
		4-6	7-9	10-12	13-15	16-18	19-21	22-24
Type 16 (1913)		—	—	—	—	—	—	—
Type 35 (1913)		—	—	—	—	—	—	1
F_1 Type 16 × Type 35 (1913)		—	—	—	—	—	—	1
Type 16 (1912)		—	—	—	3	16	20	24
Type 35 (1912)		—	—	—	1	10	18	19
F_2 Type 16 × Type 35 (1912)		—	—	6	14	59	75	89
	1912							
Type 16 (1913)		—	—	—	—	—	—	—
Type 35 (1913)		—	—	—	—	—	—	1
F_3 Type 16 × Type 35 (1913)								
15	Jan. 11th	—	—	—	—	—	—	—
8	Jan. 15th	—	—	—	—	—	—	—
163	Jan. 15th	—	—	—	—	—	—	—
27	Jan. 19th	—	—	—	—	—	4	20
190	Jan. 19th	—	—	—	—	—	—	1
202	Jan. 21st	—	—	—	—	—	—	5
251	Jan. 21st	—	—	—	—	—	—	—
35	Jan. 23rd	—	—	—	—	—	—	—
9	Jan. 24th	—	—	—	—	—	—	—
231	Jan. 24th	—	—	—	—	—	—	—
142	Jan. 27th	—	—	—	—	—	—	—
200	Jan. 31st	—	—	—	—	—	—	—

	Date of Flowering of Parent.	January.						
		4-6	7-9	10-12	13-15	16-18	19-21	22-
Type 23 (1913) ..		—	—	—	—	—	—	1
Type 38 (1913) ..		—	—	—	—	—	—	—
F_1 Type 23 × Type 38 (1913)		—	—	—	—	—	—	1
Type 23 (1912) ..		—	—	1	—	1	24	2
Type 38 (1912) ..		—	—	—	—	—	1	
F_2 Type 23 × Type 38 (1912)		—	1	—	4	6	62	8
	1912							
Type 23 (1913) ..		—	—	—	—	—	—	1
Type 38 (1913) ..		—	—	—	—	—	—	—
F_3 Type 23 × Type 38 (1913)								
104	Jan. 24th	—	—	—	—	1	3	[illegible]
155	Jan. 24th	—	—	—	—	—	—	
213	Jan. 21st	—	—	—	—	—	—	
159	Jan. 23rd	—	—	—	—	—	—	
111	Jan. 25th	—	—	—	—	—	—	
204	Feb. 2nd	—	—	—	—	—	—	
6	Jan. 23rd	—	—	—	—	—	—	
117	Jan. 31st	—	—	—	—	—	—	
9	Jan. 26th	—	—	—	—	—	—	

× Type 35.

	February.							March.					
-8	9-11	12-14	15-17	18-20	21-23	24-26	27-1M.	2-4	5-7	8-10	11-13	14-16	17-19
10	10	6	1	1	—	—	—	—	—	—	—	—	—
8	9	5	2	2	1	—	—	—	—	—	—	—	—
18	7	2	2	2	1	—	—	—	—	—	—	—	—
1	—	—	—	—	—	—	—	—	—	—	—	—	—
3	—	1	—	—	—	—	—	—	—	—	—	—	—
1	1	1	—	—	—	—	—	—	—	—	—	—	—
10	10	6	1	1	—	—	—	—	—	—	—	—	—
8	9	5	2	2	1	—	—	—	—	—	—	—	—
28	39	30	5	6	3	4	1	—	1	—	—	—	—
4	21	32	21	27	10	10	5	3	—	—	—	—	—
17	22	14	14	2	3	1	1	—	1	—	—	—	—
6	9	8	1	3	—	—	—	—	—	—	—	—	—
9	12	11	9	7	3	—	—	—	—	—	—	—	—
0	27	16	4	—	—	—	—	—	—	—	—	—	—
1	25	17	8	2	2	—	1	—	—	—	—	—	—
7	26	40	28	16	7	4	2	1	—	—	—	—	—
1	25	13	12	4	3	—	1	—	—	—	—	—	—
0	19	27	9	8	2	3	—	—	—	—	—	—	—
1	32	32	17	13	6	5	4	1	—	—	—	—	—
0	8	19	26	25	23	21	4	3	2	—	—	—	—

23 × Type 38.

	February.							March.					
8	9-11	12-14	15-17	18-20	21-23	24-26	27-1M.	2-4	5-7	8-10	11-13	14-16	17-19
—	1	—	—	—	—	—	—	—	—	—	—	—	—
7	7	4	3	1	—	—	—	—	—	—	—	—	—
0	13	3	2	—	—	—	—	—	—	—	—	—	—
1	—	—	—	—	—	—	—	—	—	—	—	—	—
8	—	1	—	—	—	—	—	—	—	—	—	—	—
4	—	—	—	—	—	—	—	—	—	—	—	—	—
—	1	—	—	—	—	—	—	—	—	—	—	—	—
7	7	4	3	1	—	—	—	—	—	—	—	—	—
0	6	1	2	—	1	—	—	—	—	—	—	—	—
9	11	4	1	1	2	—	—	—	—	—	—	—	—
0	18	4	2	3	—	—	—	—	—	—	—	—	—
0	9	4	2	2	—	—	—	—	—	—	—	—	—
0	7	3	5	2	—	—	—	—	—	—	—	—	—
6	13	5	4	5	1	—	1	—	—	—	—	—	—
7	25	14	9	4	3	1	—	—	—	—	—	—	—
6	25	20	11	3	2	2	—	—	—	—	—	—	—
6	23	20	21	11	13	7	3	—	1	—	—	—	—

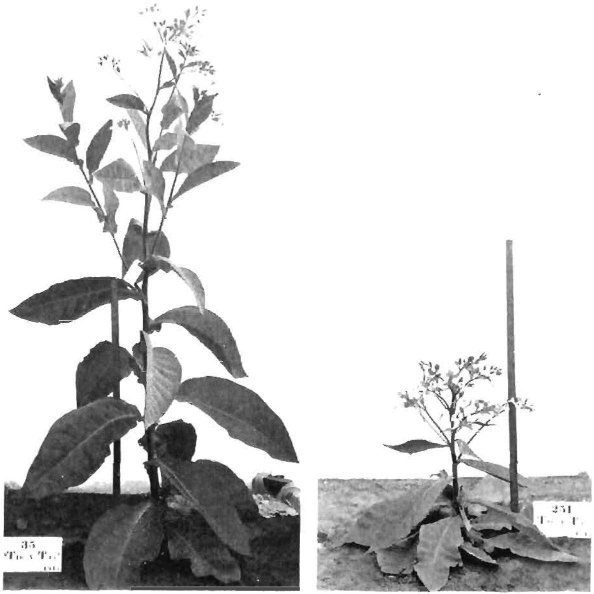
other hand, given rise only to late plants. The difference between the cultures derived from 738 and 694 was most marked in the plot. There is a good deal of difference between the individual cultures of 694. No. 694-1 has a maximum flowering period between the two parents, while 23 and 38 are much later than Type 51, the late parent. It is impossible to say whether a culture is pure as regards its time of flowering until it has been proved impossible to produce from it by selection cultures differing in this character, but 738-19 and 738-81 may possibly prove constant, as may also some of the cultures of 694.

If we consider the F_4 cultures as a whole, we find a very distinct separation as regards the flowering period. In addition, while one culture has been isolated, which is slightly earlier than the early parent, there are several which are decidedly later than Type 51, the late parent. The range of the earliest flowering culture does not overlap that of the latest.

Tables II and III show the same general results for other crosses, but the separation between the cultures is not so great, as the flowering period of the parents is not very different in either case. The extremes in the F_3 are represented in the cross Type 16 and Type 35 (Table II) by cultures 27 and 200, and in cross Type 23 × Type 38 by cultures 104 and 9. In all three the two parents in successive years bear a similar relation to one another.

2. HEIGHT.

The height was measured from the point where the roots begin to the apex of the stem, which in *N. tabacum* ends in a capsule. Three or four flowering branches arise round this point and help to define it, but there is no difficulty in seeing either the capsule or its scar at any period in the life of the mature plant. In order to count the lower leaves, the plants were uprooted and the determinations of the height and the number of leaves were made simultaneously. The height was measured



SECOND GENERATION. TYPE 16 × TYPE 35.

to the nearest centimetre, but in order to reduce the number of data and to remove accidental inequalities, the heights are given in classes differing by five centimetres in Tables IV, V, and VI.

Height is one of the few characters which in the F_1 generation is not strictly intermediate between the two parents, and the results in the five crosses were not the same. The F_1 hybrid between Type 9 (a dwarf form) and Type 51 (a very tall form) was nearly as tall as the taller parent. The actual mean measurements were, in 1910, Type 9—68 cm., F_1—140 cm., Type 51—165 cm., and in 1912, Type 9—79.9 cm., F_1—158.0 cm. and Type 51—195.4 cm. In the cross Type 16 × Type 35, in which the respective heights were, Type 16—106.3 cm., F_1—93.7 cm. and Type 35—86.6 cm., the height is intermediate. In the other three crosses the F_1 was taller than either parent. This increase in height was slight in the case of Type 23 × Type 38, but very marked in the other two crosses. The actual measurements were Type 2, average height, 155 cm., Type 3, average height, 152 cm., F_1 200 cm., Type 51, 178 cm., F_1 Type 2 × Type 51, 195 cm. It has been suggested, in the case of maize,[1] where the F_1 is also not strictly intermediate, that this is due to the increased vigour of the hybrid plants. This may be the explanation here, but it is difficult to see why this increase should be so much more marked in some cases than in others, unless this increase in vigour be correlated with the number of factors in which the parents differ.

The F_2 generation in the cross Type 9 × Type 51 presented no striking features. A continuous series was formed within the limits of the parents.

The F_2 generation of the cross between Type 16 and Type 35 was absolutely different. These two parents do not differ very greatly in height, the average height of Type 35 in 1912 was 94.1 cm., with a range of 60 to

[1] East, *l.c.*

110 cm., that of Type 16, 125.2 cm., with a range of 110 to 140 cm. The heights in the F_2 generation varied from 48 cm. to 215 cm., and the plot presented an extraordinary mixture of dwarf and tall forms. Plate XIII shows some of the F_2 forms, photographed at an equal distance from the camera. A large number of plants were self-pollinated and twelve cultures from these were raised in the F_3 generation. These cultures could be easily divided by eye into three groups, those in which all the plants were short, that is, no taller than either parent, Nos. 251,

	Height of Parent.	Centimetres.														
		40	45	50	55	60	65	70	75	80	85	90	95	100	105	11
1910		—	—	—	—	—	Mean 68		—	—	—	—	—	—	—	-
I 1910		—	—	—	—	—	—	—	—	—	—	—	—	—	—	-
e 9 × Type 51 1910		—	—	—	—	—	—	—	—	—	—	—	—	—	—	-
e 9 × Type 51 *1911*		—	—	*12*	*13*	*14*	*16*	*25*	*41*	*42*	*44*	*56*	*49*	*57*	*40*	*4*
1 × F_1 Type 9 × Type 51 1911		—	—	—	—	—	—	—	—	3	2	1	2	3	4	
1912		—	—	—	—	—	1	2	13	8	13	2	2	—	—	-
51 1912		—	—	—	—	—	—	—	—	—	—	—	—	—	—	.
e 9 × Type 51 1912		—	—	—	—	—	—	—	—	—	—	—	—	—	—	.
e 9 × Type 51																
738—1912	82	—	—	—	2	3	14	10	21	17	12	22	17	5	9	
737—1912	114	—	—	—	—	—	—	2	2	6	2	7	11	3	6	
694—1912	137	—	—	—	—	—	—	—	—	—	1	1	2	1	2	
167—1912	145	—	—	—	—	—	—	—	—	—	—	—	—	1	2	
740—1912	157	—	—	—	—	—	—	—	—	—	—	—	—	—	—	
736—1912	160	—	—	—	—	—	—	—	—	—	—	—	—	—	—	
132—1912	?	—	—	—	—	—	—	—	—	—	—	—	—	—	—	
0 1913		—	1	3	7	7	7	2	2	—	—	—	—	—	—	
51 1913		—	—	—	—	—	—	—	—	—	—	—	—	—	—	
pe 9 × Type 51																
738— 96—1913	81	2	5	13	29	56	30	23	4	—	1	—	—	—	—	
738— 76—1913	86	—	—	—	1	2	5	16	25	30	15	24	11	14	9	
738— 15—1913	86	5	6	17	33	25	38	24	7	9	4	3	1	—	—	
738— 19—1913	?	—	1	2	2	15	20	12	10	14	8	4	2	—	—	
738— 81—1913	91	—	—	1	1	3	4	13	28	28	23	24	28	14	4	
738— 58—1913	123	—	—	—	—	—	—	—	3	9	10	23	35	28	29	
694— 1—1913	?	—	—	—	—	—	—	—	—	2	8	7	17	19	18	
694—103—1913	?	—	—	—	—	—	—	—	—	—	2	3	6	3	8	
694— 10—1913	?	—	—	—	—	—	—	—	—	—	—	—	—	3	3	
694— 23—1913	?	—	—	—	—	—	—	—	—	—	—	—	—	—	—	

Mean height *Type 9—1912, 79·9 cm.*
Type 51—1912, 195·4 cm.
F_1 Type 9 × Type 51—1912, 158 cm.
F_2 culture 740—1912, 195·2 cm.

200, 142 and 190; those in which all the plants were tall, cultures 35, 15, 9, 163; and cultures in which both short and tall plants occurred, Nos. 202, 27, 231 and 8. In the last four cultures it was quite easy to separate the tall and short plants by eye, and although neither class was uniform, the short and tall plants together did not form a perfect series. Among the cultures with short plants, two have apparently bred true, No. 251 and No. 190. In 1912, No. 251, with a height of 48 cm., was the shortest plant in the F_2 generation; in 1913, this gave

Type 51.

Centimetres.																						
5	140	145	150	155	160	165	170	175	180	185	190	195	200	205	210	215	220	225	230	235	240	T N Pl
	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	
	—	—	—	—	Mean 165			—	—	—	—	—	—	—	—	—	—	—	—	—	—	
	140	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	
	15	17	7	5	3	—	2	—	—	—	—	—	—	—	—	—	—	—	—	—	—	
	8	10	5	10	5	3	5	2	—	1	—	—	—	—	—	—	—	—	—	—	—	
	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	
	—	—	—	—	1	—	1	1	3	7	6	4	5	4	—	3	2	1	1	—	—	
	1	2	9	5	6	1	3	1	5	2	—	—	—	—	—	—	—	—	—	—	—	
	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	
	9	6	4	2	4	6	1	1	—	—	—	—	—	—	—	—	—	—	—	—	—	
	14	8	6	3	2	—	2	—	—	—	—	—	—	—	—	—	—	—	—	—	—	
	11	10	8	12	10	7	7	—	3	2	1	—	—	—	—	—	—	—	—	—	—	
	—	—	—	1	3	1	5	13	13	18	16	9	17	5	9	7	9	2	7	—	1	
	6	3	5	7	4	6	10	9	8	10	12	13	5	7	5	3	1	2	1	—	—	
	4	5	11	7	11	8	10	10	9	8	7	3	4	6	1	1	—	1	1	—	—	
	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	
	—	—	—	—	—	—	1	4	5	3	6	6	4	4	—	—	—	—	—	—	—	
	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	
	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	
	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	
	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	
	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	
	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	
	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	
	7	5	1	6	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	
	11	11	4	1	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	
	15	17	20	28	21	14	18	8	5	1	1	—	—	—	—	—	—	—	—	—	—	

Mean height Type 9—1913, 57·5 cm.
Type 51—1913, 188·3 cm.
F_4 culture 738—96—1913, 60·1 cm.
F_4 culture 738—58—1913, 98·7 cm.

	Height of Parent.	Centimetres.											
		35	40	45	50	55	60	65	70	75	80	85	90
Type 35 1911		—	—	—	—	—	—	—	—	—	Mean	87	—
Type 16 1911		—	—	—	—	—	—	—	—	—	—	—	—
F_1 Type 16 × Type 35 1911		—	—	—	—	—	—	—	—	—	—	—	—
Type 35 1912		—	—	—	—	—	1	1	—	—	1	8	5
Type 16 1912		—	—	—	—	—	—	—	—	—	—	—	—
F_2 Type 35 × Type 16 1912		—	—	1	—	3	2	7	6	20	14	19	23
Type 35 1913		—	—	—	—	—	—	—	—	2	4	13	10
Type 16 1913		—	—	—	—	—	—	—	—	—	—	—	—
F_1 Type 16 × Type 35 1913		—	—	—	—	—	—	—	—	—	2	9	21
F_3 Type 16 × Type 35													
251—1913	48	1	10	35	49	26	18	5	—	—	—	—	—
200—1913	73	—	—	1	—	2	3	11	16	28	19	36	18
142—1913	81	—	—	—	—	4	9	11	28	33	31	11	15
202—1913	83	—	—	—	—	6	6	18	27	26	20	14	14
27—1913	88	—	1	9	12	12	21	17	15	19	15	13	6
231—1913	90	—	1	2	5	6	7	10	12	16	12	16	10
8—1913	116	—	—	—	—	—	1	—	—	3	8	13	24
190—1913	131	—	—	—	—	—	—	—	1	1	—	6	15
35—1913	180	—	—	—	—	—	—	—	—	—	—	—	—
9—1913	182	—	—	—	—	—	—	—	—	—	—	—	—
163—1913	*195*	—	—	—	—	—	—	—	—	—	—	—	—
15—1913	204	—	—	—	—	—	—	—	—	—	—	—	—

Mean height Type 16—1912, 125·2 cm.
Type 35—1912, 94·1 cm.

	Parent. Cm.	Centimetres.						
		65	70	75	80	85	90	95
Type 23 1911		—	—	—	—	—	—	—
Type 38 1911		—	—	—	—	—	—	—
F_1 Type 23 × Type 38 1911		—	—	—	—	—	—	—
Type 23 1912		—	—	—	—	—	—	—
Type 38 1912		—	—	—	—	—	—	—
F_2 Type 23 × Type 38 1912		—	—	1	8	18	12	30
Type 23 1913		—	—	—	—	—	—	—
Type 38 1913		—	—	—	—	—	—	—
F_1 Type 23 × Type 38 1913		—	—	—	—	—	—	—
F_3 Type 23 × Type 38 213—1913	117	—	—	1	—	5	6	3
117—1913	102·5	1	1	1	1	10	11	11
155—1913	108	—	—	2	1	6	7	12
111—1913	128	—	—	—	—	1	2	1
159—1913	139	—	—	—	—	—	—	1
104—1913	151	—	—	—	—	—	—	—
9—1913	155	—	—	—	—	—	—	—
6—1913	166·5	—	—	—	—	—	—	—
204—1913		—	—	—	—	1	5	4

Mean height Type 23—1912, 119·1 cm.

pe 35.

Centimetres.																					Tot No. Plar
30	135	140	145	150	155	160	165	170	175	180	185	190	195	200	205	210	215	220	225	230	
—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	
—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	
ı	135	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	
—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	4
17	7	1	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	4
8	4	7	4	4	9	8	10	8	8	8	6	9	6	4	1	1	1	—	—	—	35
—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	3
—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	3
—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	6
—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	14
—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	14
—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	14
11	5	6	6	2	4	3	1	1	—	—	—	—	—	—	—	—	—	—	—	—	18
6	5	3	2	1	1	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	18
6	3	7	5	4	4	2	1	—	—	—	—	—	—	—	—	—	—	—	—	—	14
1	—	6	3	2	9	4	3	1	1	—	—	—	—	—	—	—	—	—	—	—	14
—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	18
2	4	9	6	8	14	17	18	19	17	10	6	5	2	1	—	—	—	1	—	—	14
1	1	6	7	10	14	19	16	13	4	5	2	1	—	—	—	—	—	—	—	—	1[illegible]
1	2	10	10	14	20	23	19	18	6	5	2	1	—	—	—	—	—	—	—	—	1[illegible]
2	5	6	11	8	11	10	11	15	16	11	6	8	5	7	—	—	1	—	—	—	1[illegible]

Mean height Type 16—1913, 106·3 cm.
Type 35—1913, 86·6 cm.
F_1 Type 16 × Type 35—1913, 93·7 cm.
F_2 culture 251—1913, 50·8 cm.
F_3 culture 190—1913, 102·1 cm.

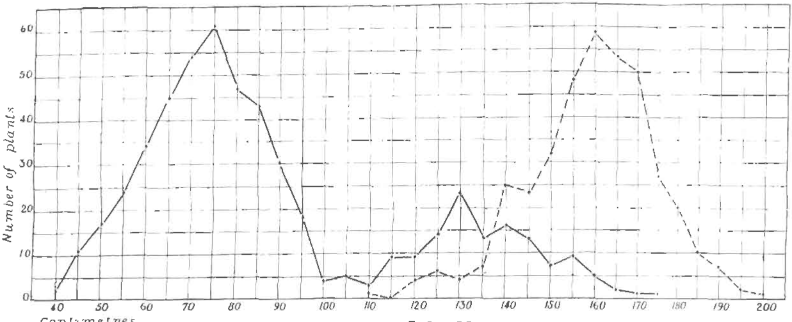
pe 38.

Centimetres.															Total No. of Plants.
35	140	145	150	155	160	165	170	175	180	185	190	195	200	205	
3	—	—	—	—	—	—	—	—	—	—	—	—	—	—	
-	—	—	—	—	—	—	—	—	—	—	—	—	—	—	
-	—	—	—	—	—	—	—	—	—	—	—	—	—	—	
1	2	—	—	—	—	—	—	—	—	—	—	—	—	—	25
1	3	5	3	2	—	1	—	—	—	—	—	—	—	—	35
8	18	10	12	5	8	3	2	4	1	1	—	—	—	—	331
1	1	—	—	—	—	—	—	—	—	—	—	—	—	—	23
4	6	2	5	1	—	—	—	—	—	—	—	—	—	—	19
-	5	5	12	7	5	7	3	2	1	—	—	—	—	—	47
2	9	6	4	1	3	1	—	1	—	—	—	—	—	—	134
9	7	—	2	3	—	1	—	—	—	—	1	—	—	—	175
8	4	6	6	2	1	1.	2	—	—	—	—	—	—	—	150
1	12	18	8	7	6	1	2	—	1	—	—	—	—	—	144
8	17	11	9	9	6	5	2	1	3	—	—	—	—	—	160
2	6	5	8	21	20	23	22	15	13	6	6	2	1	1	153
2	5	8	11	16	15	17	13	16	11	6	3	—	—	—	124
8	3	5	9	11	10	15	13	9	5	10	6	6	3	5	118
5	2	1	—	—	—	—	—	—	—	—	—	—	—	—	117

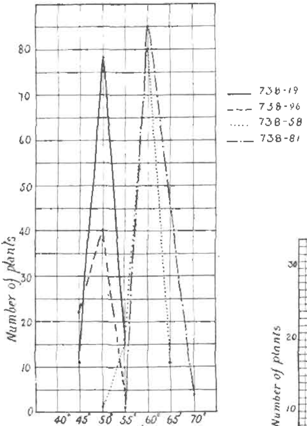
Mean height Type 23—1913, 122·9 cm.

rise to a culture which appeared absolutely uniform in the field. The average height of the culture was 50.8 cm., much less than that of Type 35, and the limits of variation (35 to 65 cm.) do not overlap those of Type 35. The individual heights of the plants, if graphically represented, give a curve which resembles greatly the ordinary frequency curve of a uniform culture. This fact, combined with the appearance of the culture in the field and the small range of its variation, makes it probable that 251 represents a culture constant as regards height. We have thus the formation in the F_3 of a new form much shorter than either parent. The factor or combination of factors which is represented by this average height of about 50 cm. may be present in both parents, or only partly in both, but the fact that this combination has been isolated shows that the height of Type 16 cannot be composed of small factors superposed on those possessed by Type 35. Even if we suppose that the combination of factors denoted by a height of 50 cm. is common to both parents, all the factors which go to form the excess of height over 50 cm. in Type 35 and Type 16 must be different. This gives the explanation of the very tall plants in the F_2 and F_3 generations. Since so large a proportion of the height in the parents is due to different gametes, the combined effect of such gametes would be additive.

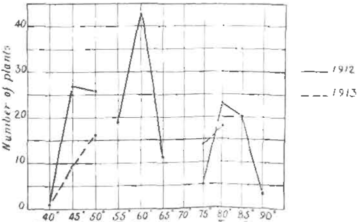
There is no definite evidence as to the number of the factors involved, but from the appearance of some of the F_3 cultures they would seem to be few in number. Culture 190 is also probably uniform and a reproduction of Type 16, the mean height in the one case being 102.1 cm., in the other 106.3 cm. The range of variation is greater, but this may be due to the larger number of plants measured. From their appearance in the field and the curves given by their height it is probable that the cultures 142 and 200 are not uniform, but represent heterozygotes between two nearly allied combinations. After 251, the most interesting culture is 202. Here we have a distinct break between the tall and the short plants,



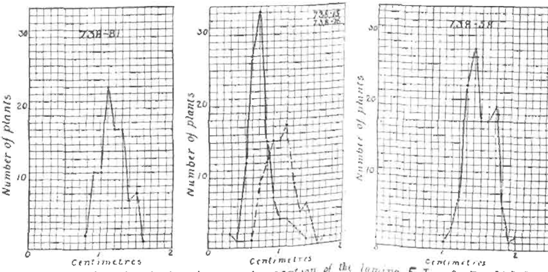
Heights in F_5 Type 35 × Type 16



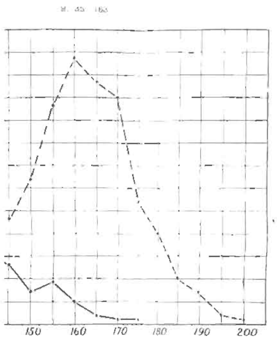
F_4 Type 9 × Type 51 - 738



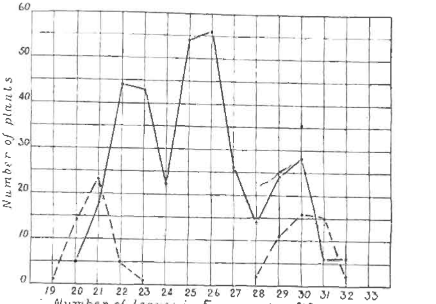
F_1 Venation



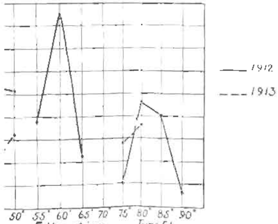
Length of the decurrent portion of the lamina F_4 Type 9 × Type 51-738.



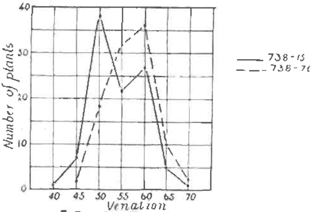
16



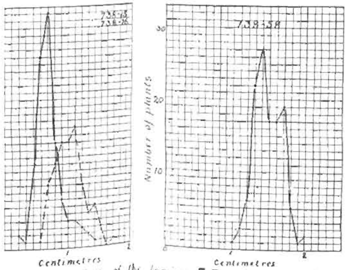
Number of leaves in F_2 generation & Parents, Type 35 x Type 16



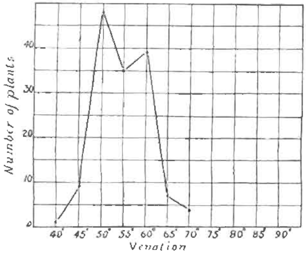
F_1 Venation Type 51



F_4 Type 9 X Type 51-738



...rrent portion of the lamina F_4 Type 9 x Type 51-738.



F_5 Type 9 x Type 51-738

and the tall plants form exactly one quarter of the whole. The large range of variation in the tall forms indicates that the ratio is not a simple 3 : 1. Cultures 27 and 231 show a similar result, an accumulation below 95 cm., a total break, or very few plants about 100 and a rise beyond this. These three cultures were derived from three F_2 plants of very similar height, 83, 88 and 90 cm. The curve formed by combining these cultures is shown in Plate XIV. Culture 8 is very similar to these three cultures, but the curve appears to be shifted to a higher value. The cultures 9, 35 and 163 are all similar and seem to point to at least two homozygotic combinations at about 120 and 170 to 180 cms., with possible intermediates. The combined curves from these three cultures is given in Plate XIV; the individual cultures all agree with this. A large number of plants have been self-pollinated and the F_4 should give sufficient uniform cultures to identify all the factors. The values obtained in some of the cultures seem somewhat high for a rudimentary height of 50cm. common to both parents. The fact that in all the cultures grown in the F_2 and F_3 nothing shorter than 50 cm. has been thrown out would point to nothing smaller than this combination existing in either; yet if this factor or combination be common to both, the mean of the highest combination possible can only be (85—50) + (106—50) + 50 cm. The limits of the tallest homozygotic combination should also throw light on another interesting point. Since every plant must have height, it is reasonable to suppose that all types possess a common factor which represents the smallest height which the tobacco plant can possess. This, either by the superposition of numerous small factors or by combination with various independent factors, gives the height of the different plants. The first supposition of small superposed factors is entirely disproved by the cross (Type 16 × Type 35), in which plants have been produced almost equivalent to the combined height of both parents, showing that the constituents of the height of both parents must be almost all different. Should a

homozygotic combination be produced equal or greater than the sum of both parents, this may be explained by the greater vigour produced by hybridization or by supposing a different rudimentary height in different plants, or that the factor giving height exists in all plants but has no definite external expression. Both these hypotheses, however, would introduce many difficulties.

The results in the cross Type 9 × Type 51 (Table IV) need not be considered in such detail. The range of variation in the F_2 was not greater than the range of the parents combined. In the F_3 generation, the eight cultures showed a great difference in the range of variation, but only one appeared to be uniform. Culture 740 (Plate XV) resembled the parent, Type 51, in every respect, both in the limits of variation and in the average height. The average height in the case of 740 was 195.2 cm., and the limits of variation 155 to 240 cm.; in the case of Type 51 the average was 195.4 cm. and the range 160 to 230 cm. Both cultures were grown side by side in the field and there was no difference in their appearance. A form resembling one of the parents was therefore isolated in the F_3. The difference in the range of variation in the F_2 and F_3 generations distinctly indicates a segregation, as well as the probable occurrence of homozygotic combinations representing heights intermediate between the two parents. One such was isolated in the F_4 generation (738-58), as well as a culture resembling Type 9 (738-96). From their appearance in the field, their range of variation and the form of the curve obtained by graphic representation, both these cultures appear to be homozygotic. The average value of the height in 738-96 is 60.1 cm., that of 738-58 is 98.7 cm. The height of culture 738-96 is probably the same as that of Type 9 (average height 57.5 cm.); the other forms a *novum*. The remaining cultures of 738 are not uniform and contain these two combinations with possibly an intermediate. The F_4 cultures of 694 are also not homogeneous, but their limits of variation are very different to

PLATE X

THIRD GENERATION. TYPE 9 × TYPE 51. NO 740.

those of the cultures obtained from 738 and indicate the occurrence of a number of intermediates. This would point to factors of small value. From the fact that no plants shorter than Type 9 have been found in all the generations, it would appear as if Type 51 must contain the factors which go to build up the height of Type 9.

In the cross between Type 23 and Type 38 the matter is complicated by the fact that the F_1 is taller than either parent. The F_2 again shows a greater range of variation than the combined range of the parents and the large number of plants shorter than Type 23, the shortest parent, is especially noticeable. In the F_3 cultures the limits of variation are very different, cf. cultures 204 and 6. The occurrence of plants shorter than Type 23 is again marked. No cultures uniform in height have yet been obtained from this cross. Distinct segregation is, however, apparent, and there are indications that Type 23 and Type 38 contain certain factors in common which give a height somewhere about 80-85 cm. and that the other factors involved in the height of both parents are different, giving rise by combination to plants taller than either parent.

3. THE NUMBER OF LEAVES PER PLANT.

This character is somewhat unsatisfactory on account of the amount of variation in each pure type, in proportion to the total variation possible between the types. The smallest number of leaves found in any kind is nineteen, the greatest thirty-four. Table VII shows the approximate number of leaves in each type—the average number of leaves in ten plants. Want of time prevented the measurement of a larger number of plants. It will be seen that every possible number of leaves present and all occur with approximately equal frequency.

The total number of leaves on the main stem was measured in the following manner. The plants were uprooted, the large roots cut off short, and the base of the plant well washed. It was then possible to count all the leaf scars as well as the living

TABLE VII.

Average Number of Leaves in the Types of *N. tabacum*.

	No. of Leaves.		No. of Leaves.		No. of Leaves.
Type 41	19·5	Type 17	23	Type 37	26
,, 40	20	,, 44	23	,, 1	26
,, 23	20	,, 45	23	,, 10	27
,, 42	20	,, 24	24	,, 39	27
,, 43	20·5	,, 27	24	,, 8	27
,, 34	20·5	,, 15	24	,, 50	28
,, 35	21	,, 7	24	,, 46	28
,, 36	21	,, 11	24	,, 51	29
,, 47	22	,, 26	25	,, 4	29
,, 48	22	,, 49	25	,, 16	30
,, 13	22	,, 25	25·5	,, 31	31
,, 6	22	,, 30	26	,, 5	33
,, 12	22	,, 2	26	,, 38	34

leaves. Enumeration at the base, where the scars are close together, is facilitated by marking the point of commencement with a knife, and each subsequent scar by sticking into it the point of a lead pencil. Care is necessary not to mistake contractions in the main root for leaf scars, but with a little practice this can be done fairly easily, except in the case of a few types. The determination of the last leaf on the axis is more difficult. In many types of tobacco, the leaves at the top of the stem are carried up the branches they subtend and therefore do not appear to be on the main stem. In such cases, however, there is generally a faint line running from the leaf down to the main stem. The method of enumeration adopted in these investigations has an advantage over previous methods used in that it represents the true physiological activity of the plant and not an arbitrary number.

As regards the effect of environment on the number of leaves, no special investigations have been undertaken, but the fact that the average value of this character and the range of variation in the parent forms is practically constant in different years, would indicate that changes in a normal environment have little effect. This agrees with the conclusion of Hayes that the number of leaves per plant was little affected, unless the

conditions were so unfavourable as to greatly stunt or dwarf the growth of the plant. It is possible, however, that the length of the growth period may have some influence. As stated on page 38, in 1913 a portion of the parent cultures were grown too close to a hedge and developed very slowly in consequence. These plants, when they did attain maturity, all had an abnormally large number of leaves. For instance, Type 51, instead of possessing the normal number of twenty-seven to thirty-one leaves, had thirty-one to thirty-five leaves, and a similar increase was noticeable in Type 35. Moreover, in 1913, a late season, the average values of all the parents was about one leaf greater than in 1912. Again, in 1911, another late season, the average value of Type 51 agrees with that of 1913. In the absence of further evidence this can only be put forward tentatively. The ordinary fluctuations of season have no appreciable effect. The number of leaves per plant apart from these abnormal individuals appears to be a very definite inheritable character.

Much attention has been paid, in the course of these investigations, to the question of a correlation between the the number of leaves and the height of the plant; but it is quite clear that each can be inherited independently of the other. Some of the shortest plants have the largest number of leaves. Take for instance culture 251 (Tables V and IX) in the F_3 generation of Type 16 × Type 35. This culture is uniform as regards height (av. 50.7 cm.) and uniform as regards leaves (av. 30), that is, it has a greater average number of leaves than Type 51, of which the mean height is 195.5 cm. Culture 190 of the same cross has an average height of 102.1 cm. and the average number of leaves is thirty. Such instances might be multiplied indefinitely. Cases also occur in which the culture is uniform as regards height, but not as regards number of leaves per plant (for example, 740 in the F_3 generation of Type 9 × Type 51) and vice versa. The fact that, while the height varies greatly with the season, the number of leaves remains

TABLE VIII.

Number of Leaves per Plant. Type 9 × Type 51.

	No. of Leaves in Parent.	17	18	19	20	21	22	23	24	25	26	27	28	29	30	31	32	33	34	35	36	37	38	39	40	Total No. of Plants.
		Number of Leaves.																								
Type 9 1911		—	—	1	4	12	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	17
Type 9 1912		—	—	—	2	12	12	9	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	35
Type 9 1913		—	—	1	14	32	16	3	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	66
Type 51 1911		—	—	—	—	—	—	—	—	—	—	1	1	5	1	2	—	—	—	—	—	—	—	—	—	10
Type 51 1912		—	—	—	—	—	—	—	—	—	—	6	13	9	4	1	—	—	—	—	—	—	—	—	—	33
Type 51 1913		—	—	—	—	—	—	—	—	—	—	—	5	14	5	4	1	—	1	—	—	—	—	—	—	30
F_1 Type 9 × Type 51 1912		—	—	—	—	—	—	5	16	13	3	—	—	—	—	—	—	—	—	—	—	—	—	—	—	37
F_2 Type 9 × Type 51 1911		—	3	6	11	26	17	35	41	68	58	62	67	43	52	34	40	25	23	13	5	5	4	8	1	647
Type 51 × F_1 Type 9 × Type 51 1911		—	—	—	1	—	4	5	7	12	16	18	19	24	6	4	4	—	—	—	—	—	—	—	—	120
F_3 Type 9 × Type 51																										
738—1912	20	3	7	9	18	27	27	22	21	1	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	135
737—1912	23	—	—	—	—	2	6	13	25	20	23	17	16	3	1	—	—	—	—	—	—	—	—	—	—	126
736—1912	25	—	—	—	—	—	2	12	16	20	36	16	16	8	2	2	—	—	—	—	—	—	—	—	—	130
745—1912	25	—	—	—	—	3	6	18	21	18	32	30	18	11	4	—	1	—	—	—	—	—	—	—	—	162
694—1912	26	—	—	—	3	6	18	10	10	10	12	9	4	5	4	1	—	—	—	—	—	—	—	—	—	92
167—1912	27	—	—	1	3	5	6	15	5	15	7	9	4	7	6	3	1	1	1	—	—	2	—	—	—	91
740—1912	31	—	—	—	—	—	—	—	—	6	9	19	27	23	23	9	8	4	—	—	—	—	—	—	—	128
132—1912	?	—	—	—	—	—	—	—	—	1	3	9	14	29	23	21	11	2	—	—	—	—	—	—	—	113
F_4 Type 9 × Type 51																										
738— 15—1913	19	3	7	11	28	23	13	12	4	2	1	—	—	—	—	—	—	—	—	—	—	—	—	—	—	104
738— 19—1913	?	—	4	12	28	37	9	1	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	91
738— 81—1913	21	4	15	35	26	15	3	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	98
738— 76—1913	23	—	—	—	—	—	1	14	10	20	30	11	7	2	—	—	—	—	—	—	—	—	—	—	—	95
738— 96—1913	24	—	—	—	—	5	7	7	12	13	16	10	11	7	7	4	1	—	—	—	—	—	—	—	—	100
738— 58—1913	25	—	—	5	8	13	10	13	21	7	12	7	2	1	—	—	—	—	—	—	—	—	—	—	—	99
694—103—1913	?	—	—	—	1	5	—	8	12	12	8	16	8	9	7	7	3	5	4	—	1	—	—	—	—	106
694— 10—1913	?	—	—	—	—	1	3	4	7	6	12	11	14	10	13	7	4	4	—	1	—	1	—	—	—	98
694— 1—1913	?	—	—	—	—	—	—	5	4	16	28	28	15	5	4	—	—	—	—	—	—	—	—	—	—	105
694— 23—1913	?	—	—	—	—	—	—	—	—	—	—	—	1	2	7	10	18	16	15	22	16	9	3	3	1	121

Average No. of Leaves
Type 9—1912, 21·8.
Type 9—1913, 21·1.
Type 51—1912, 28·4.
Type 51—1913, 29·5.

F_1 Type 9 × Type 51—1912, 24·4.
F_4 culture 738—19—1913, 20·4.
F_4 culture 738—81—1913, 19.4.
F_4 culture 694—1—1913, 26·5.

practically constant is further evidence that, within the same type, height and number of leaves are not correlated. This is a somewhat surprising result. It coincides, however, with the conclusion of Hayes, that the correlation between height and number of leaves was less than +.5.

The data as regards this character in the cross Type 9 × Type 51 are given in Table VIII. The F_1 generation was intermediate between the parents. The F_2 generation has a range far outside those of the parents, one of the plants having as many as forty leaves. That this is not due to accidental circumstances is shown by the reappearance of this phenomenon in one of the cultures in the F_4 generation, where the number of leaves varies from twenty-eight to forty. The eight cultures of the F_3 differed greatly in their range of variation; none were uniform. Two of these were continued in the F_4 generation, i.e., Nos. 738 and 694. From 738 two cultures were obtained, Nos. 738-81 and 738-19, which from their range of variation and the form of the curve appear to be uniform. The first has an average of nineteen leaves per plant, and a variation of seventeen to twenty-two. The latter culture, 738-19, is a replica of Type 9 as regards number of leaves. In the culture, derived from 694 only one can possibly be uniform, No. 694-1, but as the range of variation is somewhat large it may have originated from a heterozygote between two forms differing in one small factor. In either case it points to the occurrence of intermediate homozygotic combinations. Thus in the F_4 generation there have been isolated a culture (probably uniform) with a smaller number of leaves than either parents a culture with the same number of leaves as one parent, a culture which is either uniform with a number of leaves intermediate between both parents or a heterozygote between two intermediate forms, and a culture in which the majority of plants possess more leaves than either parent.

In the cross between Type 16 and Type 35 (Table IX), the F_1 is again intermediate, but approaches the parent with

Table IX.

Number of Leaves per Plant. Type 16 × Type 35.

		No. of Leaves in Parent.	Number of Leaves. 17	18	19	20	21	22	23	24	25	26	27	28	29	30	31	32	33	34	35	36	37	38	39	40	Total No. of Plants.
Type 35	1912		—	—	1	14	23	5	1	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	44
Type 35	1913		—	—	—	5	11	10	7	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	33
Type 16	1912		—	—	—	—	—	—	—	—	—	—	—	1	11	16	16	2	—	—	—	—	—	—	—	—	45
Type 16	1913		—	—	—	—	—	—	—	—	—	—	—	—	3	9	26	19	8	2	—	—	—	—	—	—	67
F_1 Type 16 × Type 35	1913		—	—	—	—	—	—	—	2	9	23	22	13	—	—	—	—	—	—	—	—	—	—	—	—	69
F_2 Type 16 × Type 35	1912		—	—	—	5	19	44	45	23	54	56	27	14	23	27	5	4	—	—	—	—	—	—	—	—	346
F_3 Type 16 × Type 35																									
	163—1913	24	—	—	—	—	1	1	5	7	20	22	22	7	4	3	2	—	—	—	—	—	—	—	—	—	94
	202—1913	24	—	—	—	—	—	—	5	9	22	45	13	9	1	—	—	—	—	—	—	—	—	—	—	—	104
	9—1913	25	—	—	—	—	—	—	—	6	10	20	15	21	15	13	2	3	—	—	—	—	—	—	—	—	105
	27—1913	26	—	—	—	—	—	—	—	2	12	10	13	13	9	6	5	4	1	—	—	—	—	—	—	—	75
	231—1913	26	—	—	—	—	—	—	—	2	4	10	15	15	18	17	12	8	6	—	—	—	—	—	—	—	107
	15—1913	27	—	—	—	—	—	2	2	4	9	11	25	11	18	7	5	5	2	—	—	—	—	—	—	—	101
	8—1913	27	—	—	—	—	—	—	—	1	5	8	6	17	25	21	20	4	—	—	—	—	—	—	—	—	107
	142—1913	27	—	—	—	—	—	—	—	—	9	8	27	25	21	11	7	—	—	—	—	—	—	—	—	—	108
	251—1913	28	—	—	—	—	—	—	—	—	—	—	1	7	14	31	34	11	7	—	—	—	—	—	—	—	105
	35—1913	29	—	—	—	—	—	—	—	—	—	—	4	16	15	30	16	10	6	5	2	—	—	—	—	—	104
	190—1913	30	—	—	—	—	—	—	—	—	—	—	1	8	18	33	30	10	8	2	—	—	—	—	—	—	110

Average No. of Leaves per Plant Type 16—1912, 30·1.
Type 16—1913, 31·4.
Type 35—1912, 20·8.
Type 35—1913, 21·6.

F_1 Type 16 × Type 35 -1913, 26·5.
F_3 culture 251—1913, 30·4.
F_3 culture 190—1913, 30·4.
F_3 culture 202—1913, 25·8.

the larger number of leaves. The limits of the F_2 generation are as great as those of the parents combined, but no greater. The curve obtained from its graphic representation (Plate XIV) points to distinct segregation, as do also the results obtained from the F_3 cultures. The following cultures appear to be uniform, Nos. 251 and 190, with an average number of thirty leaves per plant, and 202, with an average of twenty-six. This is another instance of the production of a plant possessing a number of leaves intermediate between those of the parents and breeding true.

Table X gives the results in the cross Type 23 × Type 38, which are very similar to those in Table IX. The F_1 generation again approaches the parent with the greatest number of leaves. Distinct segregation occurs in the F_3, but no cultures breeding true were found.

As regards the principles underlying the inheritance of the number of leaves per plant, there seems no doubt that this is a definite inheritable character, and that on hybridization segregation occurs with the formation of new homozygotic combinations. In dealing with the mode of inheritance we are confronted with the same difficulty as in the case of the height, namely, the impossibility of a plant without leaves. Hayes supposes a basal condition of x leaves which occurs in all tobacco plants with a number of small interchangeable factors, each of which may represent two leaves. Thus the same number of leaves per plant may in reality have been caused by different combinations of characters, i.e., twenty-two leaves may be x + AAbb or x + BBaa.

There is nothing in the results obtained in these investigations to contradict this hypothesis of a basal number of leaves combined with interchangeable factors. The results in the cross Type.9 × Type 51 appear to be a direct confirmation. But the form of the curves obtained in the F_2 generations point distinctly to the occurrence of factors of different values. If all the factors were more or less equal in value the form of the curve would be more uniform, and would not show such distinct modes.

TABLE X.

Number of Leaves per Plant. Type 23 × Type 38.

	No. of Leaves in Parent.	Number of Leaves. 17	18	19	20	21	22	23	24	25	26	27	28	29	30	31	32	33	34	35	36	37	38	39	40	Total No. of Plants.
Type 23 1912		—	3	8	11	3	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	25
Type 23 1913		—	1	8	17	13	4	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	43
Type 38 1913		—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	5	5	9	11	4	1	—	—	—	35
F_1 Type 23 × Type 38 1913		—	—	—	—	—	—	—	—	—	—	7	15	15	11	—	—	—	—	—	—	—	—	—	—	48
F_3 Type 23 × Type 38																										
104—1913	22	—	—	2	6	7	10	16	19	18	14	3	4	1	—	—	—	—	—	—	—	—	—	—	—	100
159—1913	23	—	—	—	–	3	3	6	10	17	17	17	13	8	3	1	1	—	—	—	—	—	—	—	—	99
213—1913	24	—	—	—	3	2	4	15	19	23	9	14	5	3	-	—	—	—	—	—	—	—	—	—	—	97
204—1913	24	—	—	—	—	—	—	—	9	20	27	22	9	2	1	—	—	—	—	—	—	—	—	—	—	90
155—1913	25	—	—	—	—	—	—	—	2	9	13	15	21	17	10	5	4	3	—	—	—	—	—	—	—	99
117—1913	25	—	—	—	—	—	—	1	4	7	10	8	18	17	13	6	4	3	2	—	—	—	—	—	—	93
6—1913	29	—	—	—	—	—	—	—	2	8	9	15	13	18	11	13	4	1	1	—	—	—	—	—	—	95
9—1913	30	—	—	—	—	—	—	—	—	—	—	—	2	5	11	14	13	20	18	15	5	—	—	—	—	103
111—1913	?	—	—	—	—	—	—	—	—	—	—	3	10	12	27	19	9	8	4	1	—	—	—	—	—	93

Average No. of Leaves per Plant Type 23—1912, 19·6.
Type 23—1913, 20·3.
Type 38—1913, 34·2.
F_1 Type 23 × Type 38—1913, 28·6.

4. THE ARRANGEMENT OF THE LEAVES ON THE STEM.

Besides the height and the number of leaves, the habit of growth of a tobacco plant depends on the arrangement of the leaves on the stem and on the inclination of the leaves, i.e., on their tendency to assume an upright or a drooping position. An economically profitable plant for India should possess a large number of upright leaves on a stem of medium height, the majority of the leaves being borne towards the base of the stem. The inheritance of the height of stem and of the number of leaves has been dealt with in sections 2 and 3. No definite results can be given as to the position of the leaves, but in cross Type 16 × Type 35, in which a form with drooping leaves was crossed with one in which the leaves are upright, distinct segregation with the formation of intermediates was observed. Similarly in culture 694-23 (Plate XVI) the upright character of the leaves of Type 51 was reproduced.

The results concerning the mode of inheritance of the arrangement of the leaves are not very complete, but some interesting observations were made. With regard to this character, the plants can be divided into three groups: (1) those which carry all their significant leaves at the base of the stem and in which the leaves consequently lie on the ground; (2) those in which the majority of the significant leaves are borne near the base, the rest up the stem, and (3) those in which the leaves are borne at equal intervals up the stem. This latter condition, which may be termed the "ladder type," is well seen in Type 51 and its offspring, No. 740 (Plate XV). This particular arrangement does not depend on the number of leaves or on the height of the plant. Short and tall plants alike are found of this type. Type 16 is an example of a short plant, with equal short internodes; culture No. 740 of one with equal, long internodes. In every case plants selected with this arrangement of the leaves have bred true as regards this

character. The F_3 cultures 190, 35, 15, 163 and 9, of Type 16 × Type 35 exemplified this.

The first arrangement in which all the leaves are carried at the base of the plant, and of which Type 9 is a good example, also does not depend on the number of leaves. In the F_3 culture 738-96, which bred true to this arrangement, the number of leaves varied from twenty-one to thirty-two, and apparently the plant found no difficulty in crowding these thirty-two leaves at the extreme base. The leaves were fairly narrow, otherwise the lower ones would have rapidly died from want of light and air. This rosette arrangement has never been met with in a very tall plant. It appears in plants of medium height (Plate XVI, 694-103-120), but the leaves are not quite so concentrated. The dwarf rosette forms have been bred true, but as yet no taller ones.

The second group, those plants in which the majority of the leaves are concentrated at the base, is a very variable one and contains a large number of different types which breed true. The difference in these types does not depend on the height, but appears to be influenced by large differences in the number of leaves. The same arrangement with twenty leaves and thirty-three leaves must appear dissimilar. The F_1 generation between Type 9 (rosette) and Type 51 (ladder) was of this type. It is interesting to note that in the F_3 generation besides rosette and ladder types, two different forms belonging to the second of the above groups have bred true. One with a few leaves at the base but which otherwise resembles the ladder type is shown on Plate XVI, 694-38-72. Another form with a great concentration of leaves at the base, 694-23-1, is shown on the same plate. The latter is an excellent type for economic purposes and it is hoped to obtain a useful tobacco from it. The fact that this culture, with such a profitable habit of growth for economic purposes, has been bred from two such useless forms as Type 9 and Type 51 is important.

691-38-72

694-23-1.

694-103 120.

HABIT. F_1 TYPE 9 × TYPE 51.

5. THE INSERTION OF THE LEAVES ON THE STEM.

In *N. tabacum* the leaves are amplexicaul and in many cases the lamina is decurrent. The length of this decurrent portion varies from .5 to 7 or 8 centimetres. Forms with non-decurrent leaves are also found. As this is one of the few characters in *N. tabacum* in which total absence of the character is possible, it has been investigated in some detail.

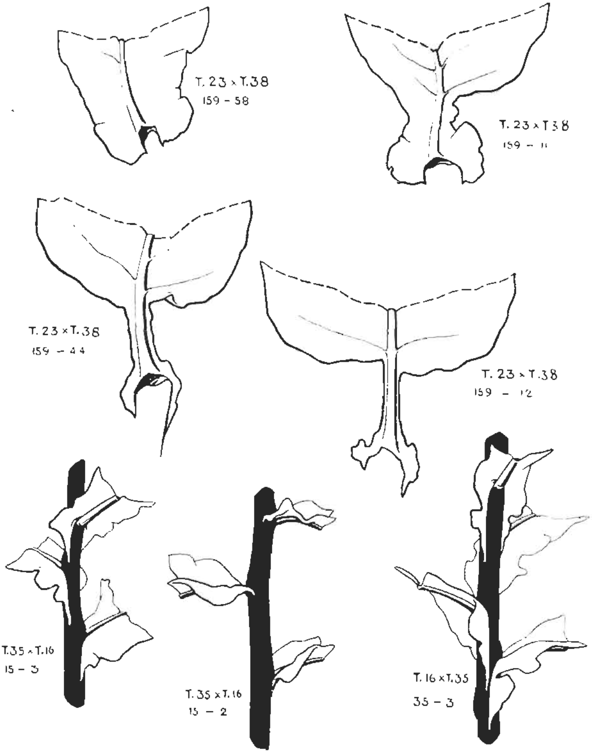
Particular attention was paid to the possibility of correlation between this and other characters such as the length of the internodes or the configuration of the base of the leaf, but as far as can be ascertained there is no relation between this character and any other. Table XI shows the lengths of the decurrent portion of the lamina of three leaves and the lengths of the three corresponding internodes in the F_3 culture 15 from the cross Type 16 × Type 35. It will be seen that there in no connection between the length of the internode and the length of the decurrent lamina. Two of the plants are figured on Plate XVII. Shortness of internode appears to have no effect in diminishing the length of the decurrent portion. Should the internode be shorter than the decurrent lamina, the latter simply grows on into the next internode past the next leaf (see Plate XVII, 35-3). At the base of the plant where the leaves are very concentrated it is true that this character cannot obtain its full expression, but there are always longer internodes above on which the real length can be observed. A limiting case might arise in which the number of leaves being very large, the plant very short and the decurrent portion very long, the latter was always stopped by the lamina of the next leaf, but such cases must be exceedingly rare, and none have been observed up to the present.

It also seems possible that the configuration of the leaf base might influence this character and that the lamina of a leaf with large auricles or a broad base would be more liable to grow down the stem. This has, however, not been found to be the case. No. 159-44, Plate XVII, shows a petiolate leaf

TABLE XI.

Length of Internode and of the Decurrent Portion of the Lamina. Type 16 × Type 35, culture 15.

Plant No.	Length of Internodes.			Length of Decurrent Portion.			Mean Length of Internode.	Mean Length of Lamina.	Plant No.	Length of Internodes.			Length of Decurrent Portion.			Mean Length of Internode.	Mean Length of Lamina.
	1	2	3	1	2	3				1	2	3	1	2	3		
19	8.0	6.5	7.0	3.4	3.2	2.9	7.2	3.2	57	6.0	5.7	5.7	3.7	4.7	4.8	5.8	4.4
44	6.7	8.0	9.3	6.2	3.3	4.0	8.0	4.5	66	8.2	7.8	6.5	4.4	3.4	4.0	7.5	2.9
36	9.0	8.5	7.0	6.4	5.5	5.7	8.2	5.9	27	9.5	8.7	8.8	5.1	5.5	6.2	9.0	5.6
73	6.1	6.6	6.1	7.0	4.1	3.5	6.3	4.9	76	4.9	4.2	4.6	4.2	4.4	4.1	4.6	4.2
1	4.0	4.6	4.0	2.6	2.0	2.2	4.2	2.3	37	6.8	7.7	6.1	5.2	5.0	6.9	6.9	5.7
60	5.0	3.9	4.0	2.0	2.0	1.9	4.3	2.0	98	9.6	7.0	7.5	5.4	3.9	3.8	8.0	4.4
83	6.4	5.7	6.0	3.2	3.0	3.2	6.0	3.1	104	6.3	6.2	6.7	5.5	7.0	5.4	6.4	6.0
91	5.9	5.2	4.6	3.0	3.2	2.7	5.2	3.0	10	5.6	5.1	5.5	4.8	4.6	4.3	5.4	4.6
20	4.0	4.8	4.1	2.3	2.0	2.1	4.6	2.1	32	5.0	4.9	4.9	4.1	5.0	4.5	4.9	4.5
47	7.2	7.4	7.1	5.3	6.2	5.9	7.2	5.8	6	8.0	6.9	6.8	4.2	4.1	4.3	7.2	4.2
33	7.3	6.5	5.2	2.5	2.1	2.1	6.3	2.2	100	8.7	9.2	8.2	3.4	3.6	2.7	8.7	3.2
16	4.7	5.4	5.5	3.0	4.2	4.5	5.2	3.9	107	8.1	8.5	7.2	7.1	6.1	5.1	7.9	6.1
23	6.9	6.2	5.1	2.4	2.6	2.8	6.1	2.6	85	5.9	5.3	5.5	1.7	1.9	2.1	5.6	1.9
39	5.3	5.9	4.5	4.9	5.2	4.7	5.2	4.9	199	4.5	4.4	4.3	2.4	2.2	1.6	4.4	2.1
21	6.1	5.2	4.4	5.1	4.7	4.2	4.9	4.7	68	7.9	7.5	6.5	6.8	5.0	6.0	7.3	5.9
42	5.3	5.6	4.7	3.4	2.6	2.4	5.2	2.8	102	6.7	7.0	6.6	4.6	4.5	4.9	6.8	4.7
2	6.7	6.0	6.4	1.4	1.8	2.1	6.4	1.8	77	7.5	7.6	6.9	6.2	6.5	8.3	7.3	7.0
84	7.2	6.2	5.5	2.7	2.6	4.0	6.3	3.1	87	8.0	8.3	7.7	2.4	3.1	3.3	8.0	2.9
92	7.3	6.9	6.4	3.9	4.4	4.2	6.9	4.2	18	3.2	4.8	3.7	2.2	2.0	2.1	3.9	2.1
34	6.2	6.5	5.6	2.7	3.0	2.6	6.1	2.8	78	5.8	5.3	4.3	3.2	2.7	3.0	5.1	3.0
29	7.2	6.5	5.5	3.9	4.5	3.9	6.4	4.1	62	4.5	4.5	3.6	4.0	4.4	4.2	4.2	4.2
50	5.0	4.2	4.3	3.7	3.5	3.4	4.5	3.5	9	4.4	4.7	4.2	3.4	3.6	4.0	4.4	3.7
49	9.3	9.1	8.4	5.6	5.4	6.3	8.9	5.8	69	7.6	6.7	6.6	3.2	4.7	3.6	7.0	3.8
65	7.2	6.9	7.0	7.7	7.6	7.2	7.0	7.5	95	4.1	3.7	4.0	4.6	4.4	4.4	3.9	4.5
8	4.5	4.2	3.3	2.7	3.2	3.1	4.0	3.0	14	4.5	4.9	3.9	2.9	3.1	2.7	4.4	2.9
58	5.5	6.1	7.5	5.2	5.0	4.1	6.7	4.8	89	6.0	5.4	5.0	4.7	4.6	4.6	5.5	4.6
63	7.0	5.7	5.5	4.9	3.6	4.0	6.1	4.2	59	6.2	7.2	6.3	4.7	5.5	4.9	6.6	5.0
71	7.2	7.3	6.8	3.5	4.2	4.3	7.1	4.0	94	8.4	9.0	7.2	2.6	3.6	3.0	8.2	3.1
81	6.8	6.2	6.7	7.3	6.4	7.4	6.6	7.0	61	4.7	5.4	4.6	1.5	1.6	1.8	4.9	1.6
90	6.3	7.6	5.3	6.3	5.2	5.7	6.4	5.7	88	9.1	8.7	7.2	4.3	4.1	3.9	8.3	4.1
80	6.6	6.6	5.2	3.2	3.5	3.7	6.1	3.5	17	8.5	6.9	7.4	5.2	8.3	5.5	7.6	6.3
100	4.9	5.1	4.7	2.7	3.9	3.8	4.9	3.5	105	7.3	7.8	6.8	3.0	3.5	3.0	7.3	3.2
24	6.0	6.2	6.1	1.7	1.9	1.4	6.1	1.7	13	6.5	6.9	5.4	5.6	6.5	6.1	6.3	6.1
26	10.6	9.3	9.1	5.8	5.3	5.2	9.7	5.4	74	6.4	6.8	7.2	4.1	4.1	3.5	6.8	3.9
12	4.4	4.3	4.1	[illegible]	2.7	3.0	4.3	2.8	72	6.0	4.7	5.3	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]



DECURRENT LEAVES.

with a long decurrent portion; No. 159-58 a broad leaf with a short one; No. 159-11, a leaf with large auricles and a short prolongation of the lamina.

Further, this character does not appear to be correlated directly with the width of the leaf.

Measurements were taken in two ways, firstly, by measuring a typical leaf on the living plant; secondly, by measuring three leaves on the plant when this had been uprooted for the observations on the height and number of leaves. The first method has the advantage that information on the inheritance of this character is available before the seed plants are chosen, the second is less fatiguing and more accurate. A large number of cultures have been examined by both methods and on normal plants either method gives good results. In this character a large amount of variation occurs, particularly in those leaves in which the decurrent portion is long. It is, however, a definitely inheritable character with distinct segregation (see Tables XIII, XV and XV). The approximate mean measurements of all the Indian types is given in Table XII (average of ten plants). It will be seen that the possibilities are numerous.

TABLE XII.

Length of the Decurrent Portion of the Lamina in the Types of *N. tabacum*.

	Cm.		Cm.		Cm.
Type 7	—	Type 3	1.5	Type 24	3.0
,, 9	—	,, 10	1.5	,, 43	3.1
,, 21	—	,, 5	1.6	,, 27	3.3
,, 12	.5	,, 17	1.9	,, 26	3.5
,, 20	.5	,, 18	2.0	,, 46	3.6
,, 6	.5	,, 1	2.0	,, 31	3.7
,, 13	.7	,, 42	2.3	,, 37	3.8
,, 11	.8	,, 2	2.5	,, 47	4.1
,, 14	.9	,, 35	2.5	,, 48	4.1
,, 36	1.1	,, 40	2.6	,, 30	4.5
,, 8	1.2	,, 39	2.6	,, 49	5.4
,, 23	1.3	,, 35	2.8	,, 51	6.0
,, 3	1.5	,, 41	2.9	,, 38	6.0

Table XIII gives the results obtained in the cross Type 9 (*non-decurrent*) × Type 51 (with an average of 6 cm.). The F_1 was intermediate between the parents and the F_2 covered the whole range between non-decurrent forms and those like Type 51. Several of the plants classed as non-decurrent in the F_2, however, gave rise to forms with decurrent laminas later (cultures 738 and 745). This may be due to the fact that in the early investigations the number of factors involved was not realized and no measurements of less than .5 centimetres were made. Great differences were observed in the F_3 generations, e.g., the cultures 738 and 132, but none of the cultures proved uniform. In 1912, unfortunately all plants in which the decurrent portion was shorter than 5 mm. were again classed as non-decurrent. Cultures 738 and 694 were continued to the F_4 generation. The results obtained from culture 738 will be considered first. Two plants which appeared similar to Type 9, were chosen for future cultivation, and four plants whose leaves were decurrent to varying amounts, 5, 7, 11 and 15 mm. Of the two cultures with non-decurrent leaves, one bred true and resembled Type 9. The other was a heterozygote. A detailed examination of Type 9 shows that occasionally the method of insertion of the leaves caused the lamina to be attached to the stem for about 3 *mm.* This makes it almost impossible to distinguish pure non-decurrent forms from the F_1 between non-decurrent leaves and those possessing the smallest factor for a decurrent lamina. In 1913 most careful measurements of all plants have been made especially in those cases where the value was below 5 mm. Three careful determinations were made in the case of all the cultures derived from 738, and the mean of these form the data given in Table XIV. The limits, within which the splitting takes place, are so small that it is very difficult to obtain really reliable information as to the extent and number of the factors, but there is no doubt of the difference between the cultures. It appears probable that two factors are involved, one giving a length of about .5 or .7 cm.; the other about 1.1 cm.,

TABLE XIII.

Length of the Decurrent Portion of the Lamina. Type 9 × Type 51.

	Parent. Cm.	Less than ·4	·5	1·0	1·5	2·0	2·5	3·0	3·5	4·0	4·5	5·0	5·5	6·0	6·5	7·0	7·5	8·0	8·5	9·0	9·5	10·0	10·5	11·0	Total No. of Plants.
		Length of Decurrent Portion of the Lamina in Centimetres.																							
Type 9 1912		52	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	52
Type 9 1913		54	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	54
Type 51 1912		—	—	—	—	—	—	—	—	—	2	6	9	13	8	8	2	3	—	—	—	—	—	—	51
Type 51 1913		—	—	—	—	—	—	—	—	—	—	2	7	13	16	5	1	—	—	—	—	—	—	—	44
F_1 Type 9 × Type 51 1913		—	—	—	1	20	30	7	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	58
F_2 Type 9 × Type 51 1911		142	55	120	94	90	72	49	24	10	4	5	1	1	—	1	—	—	—	—	—	—	—	—	668
Type 9 × F_1 Type 9 × Type 51 1911		150	42	46	31	8	—	1	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	278
Type 51 × F_1 Type 9 × Type 51 1911		—	—	4	11	23	40	22	32	32	22	12	1	4	1	—	—	—	—	—	—	—	—	—	204
F_3 Type 9 × Type 51 738—1912	Less than ·4	46	2	42	48	8	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	140
745—1912	Less than ·4	49	—	29	49	14	2	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	143
737—1912	1.0	1	12	24	41	27	13	9	4	4	—	—	—	—	—	—	—	—	—	—	—	—	—	—	135
167—1912	2.5	—	—	1	5	34	36	13	7	1	—	—	—	—	—	—	—	—	—	—	—	—	—	—	97
736—1912	3.0	—	1	3	16	28	18	32	15	7	4	1	—	—	—	—	—	—	—	—	—	—	—	—	125
740—1912	3.0	—	—	—	—	1	8	22	34	30	22	6	4	3	—	—	—	—	—	—	—	—	—	—	130
694—1912	3.5	—	—	—	3	13	18	21	17	18	5	5	—	1	—	—	—	—	—	—	—	—	—	—	101
132—1912	Like T51	—	—	—	—	—	1	4	17	22	31	18	13	5	4	1	—	—	—	—	—	—	—	—	116
F_4 Type 9 × Type 51																									
738– 96—1913	Less than .4	108	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	108
738– 19—1913	Less than .4	7	66	27	5	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	105
738– 76—1913	.5	—	11	68	15	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	94
738– 15—1913	.75	—	68	33	3	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	104
738– 81—1913	1.2	—	—	64	33	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	97
738– 58—1913	1.5	—	—	11	81	9	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	101
694– 1—1913	1.3	—	—	1	21	54	23	1	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	100
694–103—1913	2.3	—	—	2	17	17	14	22	13	11	6	—	—	—	—	—	—	—	—	—	—	—	—	—	102
694– 38—1913	3.8	—	—	—	1	7	20	36	31	12	4	—	—	—	—	—	—	—	—	—	—	—	—	—	111
694– 10—1913	4.6	—	—	—	—	—	5	15	28	16	26	6	4	1	—	—	—	—	—	—	—	—	—	—	99
694– 23—1913	6.2	—	—	—	—	—	1	4	10	35	20	11	10	8	—	—	—	—	—	—	—	—	—	—	99

TABLE

Length of the Decurrent

	Parent	Length of the Decurrent Portion of the Lamina in Millimetres.										
	mm.	0	1	2	3	4	5	6	7	8	9	10
F_3 Type 9 × Type 51 745—1912	Less than 5	49	—	—	1	—	16	1	11	10	1	14
F_3 Type 9 × Type 51 738—1912	Less than 5	46	—	—	2	30	2	10	19	—	15	6
F_4 *Type* 9 × *Type 51*												
738-19—1913	Less than 4	—	—	7	8	11	18	14	15	8	7	4
738-76—1913	5	—	—	—	—	—	1	1	9	12	15	15
738-15—1913	7.5	—	—	—	2	1	12	22	28	15	7	4
738-81—1913	12	—	—	—	—	—	—	—	—	2	11	11
738-58—1913	15	—	—	—	—	—	—	—	—	—	—	1
694- 1—1913	13	—	—	—	—	—	—	—	—	—	—	—
Type 23 1913		—	—	—	—	—	—	1	1	1	4	3
F_3 *Type* 23 × *Type* 38 155—*1913*	15	—	—	—	—	—	—	—	—	1	1	6
F_3 Type 16 × Type 35 190—1913	14	—	—	—	—	—	—	—	—	6	2	12

or there may be two factors of .5 and .7 cm. with a combination of 1.2 cm. It will be seen from the graphic representations (Plate XIV) that 738-81 with a mode at 1.1 cm. is most probably uniform, and culture 15 with a mode at .7 cm. possibly so. The number of plants with non-decurrent leaves in culture 738-19 gives a ratio, total plants: those with non-decurrent leaves, 15: 1, which would also *indicate the existence of two factors.* Further observations will be made on this point, but on account of the small size, the difficulties of measurement and interpretation are very great. Culture 694 must be considered next. This culture has *never given any plants with non-decurrent leaves.* Two cultures appear to be uniform, 694-1 with an average length of the decurrent portion of 1.8 cm., and 694-23 with an average of 4.0 cm. The detailed measurements of the culture 694-1 are also given in Table XIV, and show by their range that this cannot possibly be identical with the combination of factors in the culture 738. As the parent plant of 694-23 was the plant *with the longest and that of 694-1 the plant with the* shortest decurrent portion in the F_3 culture 694, it is probable that 4.0 cm. the mean value of 694-23 represents the combination of the factor or factors of 694-1 with another or *others. The existence of at least three or four factors which*

XIV.

Portion of the Lamina.

Length of the Decurrent Portion of the Lamina in Millimetres.																				Total No. of Plants.
11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30	
15	9	8	1	3	1	1	—	—	1	1	—	—	—	—	—	—	—	—	—	143
8	5	—	2	—	1	—	—	—	—	—	—	—	—	—	—	—	—	—	—	148
5	3	2	1	—	1	1	—	—	—	—	—	—	—	—	—	—	—	—	—	105
17	0	5	6	3	—	1	—	—	—	—	—	—	—	—	—	—	—	—	—	94
4	3	2	1	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	101
22	17	17	7	8	1	—	—	—	—	—	—	—	—	—	—	—	—	—	—	96
3	7	17	22	13	13	15	6	1	2	—	—	—	—	—	—	—	—	—	—	100
—	1	2	—	11	3	5	18	2	16	1	17	9	2	6	4	2	1	—	—	100
1	8	8	6	5	—	3	1	—	2	—	—	—	—	—	—	—	—	—	—	44
1	5	14	9	6	2	4	5	—	—	1	3	—	—	—	—	—	—	—	—	58
4	11	20	9	9	3	11	11	—	6	—	2	—	1	—	—	—	—	—	1	108

combine to make up the length of the decurrent portion of the lamina in Type 51 is therefore probable.

The results in cross Type 16 × Type 35 (Table XV), are also interesting. Here both parents have the same average value, and the range of variation in the F_1 generation is exactly similar to that of the parents. The length in the F_2 generation varies from .5 cm. to 6.5 cm., far beyond the limits of the parents. No plants with non-decurrent leaves were found, but this may have been due to the comparatively small number measured. In the third generation there were great differences among the cultures, and plants with non-decurrent leaves occurred in three cultures. The numbers in all these cases (cultures 231, 202, 27) point to a 63 : 1 ratio and consequently to the existence of three factors in these particular cultures. Higher values were found in the F_2 than in these cultures indicating the existence of additional factors in the parents. This supposition is confirmed by the high values found in the F_3 culture 163. The large number of factors involved would explain the absence of plants with non-decurrent leaves in the F_2. The factors which are responsible for the length of the decurrent portion of the lamina in Types 16 and 35 respectively would seem to be entirely different, even though their external expression is identical.

Culture 163 probably represents the combination of all the factors in Type 16 and Type 35. The total variation is no greater than in Type 51. The average value in this culture is greater than the combined average values of Type 16 × Type 35, but this may be due to the added vigour due to hybridization. Further cultures will, it is hoped, put the matter beyond question, and any explanation must be tentative until these have been examined. Culture 190 is probably uniform with regard to this character.

The cross Type 23 × Type 38 (Table XVI) is similar to that between Type 9 and Type 51, except that neither parent has non-decurrent leaves. The F_1 is intermediate and the range of variation in the F_2 generation is the same as that covered by both parents. It would seem therefore as if the same combination of factors was common to both parents with the addition of extra factors in one parent. Culture 155 is uniform and like Type 23, culture 104 is possibly uniform and like Type 38, but this cannot be assumed safely until further cultures are raised, as the variability is somewhat great. The parent Type 38 and the F_1 generation exhibit very great variation in the same plant.

6. VENATION OF THE LEAVES.

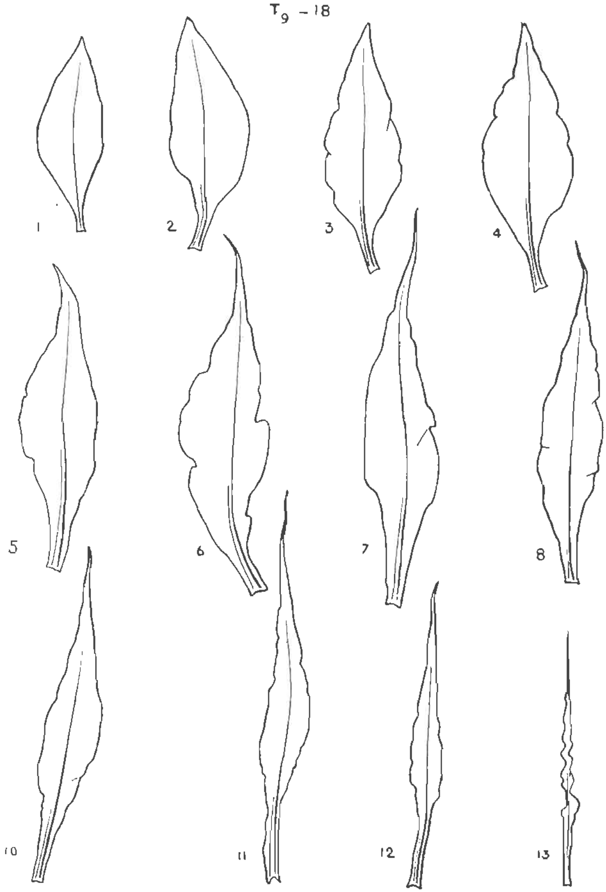
The characters of the lamina itself will now be considered and of these the venation has proved to be the most constant and easily measured. A few words of explanation as regards the choice of the material are necessary, and the following explanation refers to all measurements on the leaves themselves. The leaves of a tobacco plant are not all of the same kind, the lower or ground leaves are very much alike in all the types and are not characteristic of the variety. They are almost invariably flat, and have a venation of 60°. This is the case even in Type 9, in which the upper leaves are twisted by excess of undulation. These ground leaves pass by a fairly rapid gradation into the significant leaves, which are typical of the variety, and comprise most of the leaves on the plant. The significant leaves increase

Table XV.

Length of the Decurrent Portion of the Lamina. Type 16 × Type 35.

	Parent. Cm.	Less than ·4	·5	1·0	1·5	2·0	2·5	3·0	3·5	4·0	4·5	5·0	5·5	6·0	6·5	7·0	7·5	8·0	8·5	9·0	9·5	10·0	10·5	11·0	Total No. of Plants.
		Length of the Decurrent Portion of the Lamina in Centimetres.																							
Type 16 1912		—	—	—	—	11	31	23	9	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	74
Type 16 1913		—	—	—	—	3	12	18	4	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	37
Type 35 1912		—	—	—	—	15	26	20	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	61
Type 35 1913		—	—	—	—	15	18	2	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	35
F_1 Type 16 × Type 35 1913		—	—	—	—	20	35	9	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	64
F_2 Type 16 × Type 35 1912		—	7	19	37	36	50	32	33	19	12	7	6	2	2	—	—	—	—	—	—	—	—	—	262
F_3 Type 16 × Type 35																									
142—1913	·5	—	15	63	27	2	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	107
231—1913	·8	2	8	40	25	20	7	4	–	1	—	—	—	—	—	—	—	—	—	—	—	—	—	—	107
202—1913	1·2	3	8	33	40	16	11	14	7	5	—	2	2	—	—	—	—	—	—	—	—	—	—	—	141
27—1913	1·2	2	22	38	20	16	7	2	2	1	—	—	—	—	—	—	—	—	—	—	—	—	—	—	110
251—1913	1·3	—	10	51	40	6	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	107
190—1913	1·4	—	—	35	52	19	1	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	107
8—1913	3·3	—	—	—	—	1	12	11	21	17	18	9	9	5	1	—	—	—	—	—	—	—	—	—	104
200—1913	3·5	—	—	—	1	13	27	27	20	10	4	1	2	1	—	—	—	—	—	—	—	—	—	—	106
9—1913	3·8	—	—	—	—	—	1	11	22	27	28	27	10	8	4	1	—	—	—	—	—	—	—	—	139
15—1913	3·8	—	—	—	4	8	8	10	10	17	13	11	9	4	7	3	2	—	—	—	—	—	—	—	106
35—1913	5·5	—	—	—	—	—	1	1	4	11	12	12	13	8	14	9	7	5	2	3	2	—	—	—	104
163—1913	6·8	—	—	—	—	—	—	—	—	—	1	3	15	28	22	13	11	6	1	—	—	—	—	—	100

slowly in size from the base and then diminish at the top of the plant, the diminution increasing very rapidly at the end. The leaves in the centre of the plant are approximately uniform in most of the types. Above the significant leaves come a few very small leaves which vary greatly in shape. In some of the broad-leaved types, they are small replicas of the large leaves; in types with lanceolate leaves they are linear; while in many cases they may be linear even if the significant leaves are not lanceolate. In Tables XVII, XVIII, and XIX detailed measurements are given of all the leaves on three plants of each of the parents. Unfortunately, by the time the plant is mature, the lower leaves have become damaged. The large number of fairly uniform leaves in the centre of the plant is, however, evident. Type 9 (Table XVII and Plate XVIII) is an example of an extreme case in which no two leaves are alike. The best material for all leaf measurements is undoubtedly to be found in the central leaves, which are practically uniform, and all the measurements in this paper have been taken on such typical leaves. It is impossible to choose any definite leaf (for example, the tenth leaf) suitable to all plants owing to the variations in the number of leaves per plant, but it is quite easy with practice to pick out the middle portion of the plant by eye and to select a typical leaf in this position. The tables show that in this region of the plant there are a large number of leaves, all of which are suitable. Measurements carried out on the parents by taking a typical leaf from a large number of plants have shown that the method is most satisfactory. The usual practice of obtaining the average between the bottom, the middle and the top leaf is open to many objections and would be quite unsuitable for the kinds of tobacco grown in India. It presupposes a uniform change in the size of the leaves on the plant, and takes no account of the large number of uniform leaves in the centre of the plant, which vary in their effect on the average with the number of leaves per plant, and the type of the plant. Moreover, the determination of the top leaf is necessarily arbitrary. The real top leaves are far too small



THE LEAVES OF A SINGLE PLANT (TYPE 9).

TABLE XVI.

Length of the Decurrent Portion of the Lamina. Type 23 × Type 38.

		Parent. Cm.	·4	·5	1·0	1·5	2·0	2·5	3·0	3·5	4·0	4·5	5·0	5·5	6·0	6·5	7·0	7·5	8·0	8·5	9·0	9·5	10·0	10·5	11·0	Total No. of Leaves.
Type 23	1912		—	—	26	45	3	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	74
Type 23	1913		—	—	5	18	3	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	26
Type 38	1912		—	—	—	—	—	—	—	—	2	3	14	14	14	14	15	2	—	—	—	—	—	—	—	78
*Type 38	1913		—	—	—	—	—	—	—	—	—	—	—	3	1	10	11	6	4	2	—	—	—	—	—	37
*F_1 Type 23 × Type 38	1913		—	—	—	—	—	2	7	13	9	11	3	2	—	1	—	—	—	—	—	—	—	—	—	48
F_2 Type 23 × Type 38	1912		—	—	9	9	32	34	54	41	44	33	25	20	14	7	4	5	3	—	—	—	—	—	—	343
F_3 Type 23 × Type 38																										
204	1913	1.3	—	—	15	31	31	11	8	2	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	98
155	1913	1.5	—	—	14	25	9	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	48
*117	1913	2.6	—	—	2	13	20	17	13	10	13	1	3	1	—	—	—	—	—	—	—	—	—	—	—	93
159	1913	2.9	—	—	—	9	32	26	21	7	5	5	3	1	1	—	—	—	—	—	—	—	—	—	—	110
6	1913	4.5	—	—	1	—	6	15	20	18	15	14	9	7	3	2	2	—	—	—	—	—	—	—	—	112
213	1913	4.5	—	—	1	4	12	16	20	19	21	3	5	3	—	—	—	—	—	—	—	—	—	—	—	104
*9	1913	—	—	—	—	—	2	13	18	15	20	14	8	3	6	2	—	—	—	—	—	—	—	—	—	101
*111	1913	6.6	—	—	—	—	—	3	9	11	16	7	9	10	4	11	6	6	3	2	—	—	1	—	—	96
*104	1913	7.2	—	—	—	—	—	—	—	—	—	1	10	15	11	16	17	14	5	5	1	2	—	—	—	97

In the plants marked * the values given are the mean of three determinations.

Table XVII.

Dimensions of Lamina. Types 9 and 51.

(Measurements in Centimetres.)

No. of Leaf.	Venation.	Breadth.	Length.	Length/Breadth.	Venation.	Breadth.	Length.	Length/Breadth.	Venation.	Breadth.	Length.	Length/Breadth.
						Type 9.						
		Plant 1.				Plant 2.				Plant 3.		
1	Damaged				Damaged				Damaged			
2	,,				,,				,,			
3	,,				,,				,,			
4	40°	14.6	38.5	2.6	35°	12.8	33.8	2.6	35°	11.6	31.5	2.7
5	30°	15.3	44.0	2.9	40°	16.0	42.0	2.6	40°	12.6	39.0	3.1
6	40°	17.6	51.7	3.0	40°	15.0	45.4	3.0	40°	15.0	48.0	3.2
7	45°	17.8	57.0	3.2	45°	17.9	49.0	2.8	45°	17.0	50.6	3.0
8	45°	15.7	56.0	3.5	50°	15.0	53.4	3.5	50°	14.0	—	—
9	50°	17.2	70.4	4.1	45°	17.4	64.1	3.7	45°	13.2	58.0	4.4
10	50°	11.7	65.3	5.6	50°	14.7	70.2	4.8	50°	12.3	59.7	4.8
11	50°	14.3	60.0	4.2	45°	11.2	60.3	5.4	50°	11.5	61.0	5.3
12	50°	14.9	74.3	5.0	50°	12.0	70.0	5.8	45°	12.1	72.0	6.0
13	50°	9.3	65.0	7.0	50°	10.6	63.4	6.0	50°	10.7	53.5	5.0
14	50°	8.3	63.5	7.6	45°	8.8	69.7	8.0	45°	7.0	59.5	8.5
15	55°	8.2	67.0	8.2	50°	6.1	52.5	8.6	45°	7.1	65.8	9.3
16	50°	4.5	53.0	11.8	—	2.9	44.6	15.3	—	5.0	53.8	10.8
17	—	3.2	51.5	16.1	remainder not measured.				—	3.4	46.0	13.5
18	remainder not measured.								remainder not measured.			
						Type 51.						
		Plant 1.				Plant 2.				Plant 3.		
1	Damaged				Damaged				Damaged			
2	,,				,,				,,			
3	,,				,,				,,			
4	,,				,,				,,			
5	75°	13.0	37.0	2.8	75°	17.4	34.5	2.0	,,			
6	75°	17.9	33.7	1.9	70°	17.6	35.9	2.0	70°	17.3	35.0	2.0
7	75°	19.1	37.0	1.9	75°	23.2	42.8	1.8	75°	18.4	36.1	2.0
8	80°	21.4	42.0	1.9	75°	23.2	44.7	1.9	70°	20.7	41.3	2.0
9	75°	21.5	42.3	1.9	75°	26.7	48.0	1.8	75°	24.7	47.5	1.9
10	80°	23.9	14.3	1.8	80°	26.8	48.6	1.8	80°	23.8	46.1	1.9
11	75°	24.2	48.7	2.0	80°	24.6	48.1	1.9	80°	25.3	47.1	1.9
12	80°	24.7	46.0	1.9	80°	27.1	50.5	1.9	80°	25.4	47.4	1.9
13	80°	23.8	46.9	2.0	80°	27.6	48.8	1.8	80°	26.8	48.6	1.8
14	80°	25.6	46.3	1.8	85°	29.0	40.3	1.7	80°	25.9	47.2	1.8
15	80°	27.1	46.8	1.7	75°	28.3	45.9	1.6	80°	25.6	46.7	1.8
16	80°	25.3	47.2	1.9	80°	26.4	47.0	1.8	80°	25.7	44.8	1.7
17	85°	26.0	43.1	1.7	80°	27.7	45.2	1.6	80°	27.1	46.7	1.7
18	85°	22.5	40.7	1.8	80°	28.8	43.4	1.5	80°	25.0	42.6	1.7
19	85°	24.2	40.4	1.7	85°	24.0	42.0	1.75	80°	24.2	40.1	1.7
20	85°	24.0	39.2	1.6	80°	26.6	41.8	1.6	85°	22.0	39.2	1.8
21	85°	20.8	36.8	1.8	80°	24.9	39.4	1.6	80°	24.2	38.0	1.6
22	80°	23.5	34.2	1.5	80°	26.1	39.0	1.5	80°	21.7	35.3	1.6
23	80°	19.8	32.7	1.7	75°	21.8	34.3	1.6	85°	20.3	32.8	1.6
24	80°	18.3	30.8	1.7	80°	15.3	27.0	1.8	80°	18.9	28.6	1.5
25	75°	15.5	25.2	1.6	80°	14.6	24.6	1.7	70°	13.4	24.6	1.8
26	75°	9.9	18.8	1.9	70°	8.4	18.0	2.1	70°	9.4	17.8	1.9
27	—	6.8	14.8	2.2	—	5.5	14.0	2.5	remainder not measured.			
28	remainder not measured.				remainder not measured.							

Table XVIII.

Dimensions of Lamina. Types 35 and 16.

(Measurements in Centimetres).

Type 35.

No. of Leaf.	Plant 1. Venation.	Breadth.	Length.	Length. / Breadth.	Plant 2. Venation.	Breadth.	Length.	Length. / Breadth.	Plant 3. Venation.	Breadth.	Length.	Length. / Breadth.
1	Damaged				Damaged				Damaged			
2	,,				,,				,,			
3	,,				,,				,,			
4	,,				,,				,,			
5	,,				70°	18.3	32.3	1.8	65°	16.7	28.6	1.7
6	70°	22.1	31.1	1.4	70°	24.0	35.5	1.5	65°	20.6	33.0	1.6
7	75°	27.4	34.3	1.3	70°	24.7	38.7	1.6	70°	25.4	39.0	1.5
8	80°	26.8	—	—	75°	31.0	45.5	1.5	70°	26.3	40.8	1.5
9	80°	31.8	44.3	1.4	80°	33.1	49.0	1.5	75°	25.3	39.8	1.6
10	80°	25.5	45.5	1.8	80°	29.9	45.6	1.5	80°	34.0	49.2	1.5
11	80°	31.0	48.7	1.6	80°	34.8	52.6	1.5	80°	30.4	50.0	1.6
12	30°	30.7	48.0	1.6	80°	27.1	46.4	1.7	80°	28.4	48.2	1.7
13	80°	28.1	45.3	1.6	80°	30.8	49.9	1.6	80°	33.0	52.3	1.6
14	80°	33.3	49.1	1.5	75°	35.8	54.4	1.5	80°	26.7	43.6	1.6
15	80°	29.0	41.2	1.4	80°	29.2	43.3	1.5	80°	30.5	49.0	1.6
16	80°	32.3	46.3	1.4	80°	32.2	46.1	1.5	80°	28.0	41.9	1.5
17	80°	29.7	39.5	1.3	85°	26.8	39.5	1.5	80°	19.3	33.1	1.6
18	80°	22.7	33.2	1.5	85°	16.4	25.5	1.6	80°	19.5	30.9	1.6
19	80°	20.0	29.0	1.5	75°	11.1	19.6	1.8	75°	9.8	19.0	1.7
20	75°	12.3	20.4	1.7	remainder not measured.				60°	5.0	12.8	2.4
21	60°	4.8	12.8	2.7					remainder not measured.			
22	remainder not measured.											

Type 16.

No. of Leaf.	Plant 1. Venation.	Breadth.	Length.	Length. / Breadth.	Plant 2. Venation.	Breadth.	Length.	Length. / Breadth.	Plant 3. Venation.	Breadth.	Length.	Length. / Breadth.
1	Damaged				Damaged				Damaged.			
2	,,				,,				,,			
3	,,				,,				,,			
4	,,				60	6.1	21.3	3.5	,,			
5	,,				Damaged				,,			
6	50°	7.8	30.8	4.0	60°	7.8	28.0	3.6	55°	8.2	29.7	3.6
7	55°	7.0	25.0	3.6	50°	7.5	30.8	4.1	60°	8.6	31.2	3.6
8	50°	9.1	35.6	3.9	50°	9.0	36.6	4.1	50°	9.7	39.0	4.0
9	55°	8.7	36.2	4.2	50°	8.8	34.7	3.9	60°	9.8	38.7	4.0
10	50°	10.7	43.1	4.0	55°	9.1	41.7	4.6	55°	10.7	41.2	3.9
11	50°	10.2	41.7	4.1	45°	9.5	—	—	50°	10.9	46.3	4.2
12	55°	11.0	46.3	4.2	50°	9.9	41.9	4.2	55°	12.0	45.7	3.8
13	50°	12.5	51.6	4.1	50°	10.5	44.6	4.2	50°	12.4	48.5	3.9
14	45°	12.2	47.4	3.9	50°	10.1	41.0	4.1	55°	11.9	48.1	4.0
15	45°	11.7	52.2	4.5	55°	10.5	43.4	4.1	50°	12.7	49.0	3.9
16	50°	11.1	46.9	4.2	50°	10.4	43.6	4.2	50°	12.3	—	—
17	50°	12.1	49.4	4.1	50°	10.5	44.4	4.2	55°	11.5	45.7	4.0
18	50°	13.0	51.7	4.0	50°	11.5	43.8	3.8	50°	12.8	50.3	3.9
19	50°	12.4	48.3	3.9	50°	9.7	41.7	4.3	50°	11.3	48.8	4.3
20	50°	13.0	51.5	4.0	50°	10.0	42.7	4.3	50°	12.3	47.0	3.8
21	45°	11.4	48.1	4.2	50°	10.0	41.4	4.1	50°	10.3	42.0	4.0
22	55°	11.8	48.3	4.1	50°	9.7	40.0	4.1	60°	10.5	40.3	3.8
23	50°	12.0	46.4	3.9	50°	9.2	38.9	4.2	50°	10.5	43.8	4.2
24	50°	9.8	40.4	4.1	50°	8.6	37.5	4.4	55°	9.5	39.0	4.1
25	50°	10.6	39.3	3.7	50°	8.5	38.9	4.6	50°	9.0	36.6	4.0
26	45°	7.0	31.6	4.5	50°	7.7	34.9	4.5	55°	9.2	36.6	4.0
27	45°	5.7	27.0	4.7	45°	6.8	32.5	4.8	50°	6.5	28.0	4.3
28	—	2.9	19.6	6.8	45°	6.2	29.1	4.7	50°	5.4	24.8	4.6
29	remainder not measured.				—	4.4	21.8	5.0	—	2.4	16.8	7.0
30					remainder not measured.				remainder not measured.			

Table XIX.

Dimensions of Lamina. Types 23 and 38.

(Measurements in Centimetres.)

No. of Leaf.	Venation.	Breadth.	Length.	Length / Breadth.	Venation.	Breadth.	Length.	Length / Breadth.	Venation.	Breadth.	Length.	Length / Breadth
						Type 23.						
	Plant 1.				Plant 2.				Plant 3.			
1	Damaged				Damaged				Damaged			
2	,,				,,				,,			
3	,,				,,				,,			
4	,,				,,				,,			
5	,,				,,				70°	18.2	33.5	1.8
6	65°	13.2	33.7	2.6	70°	22.0	44.8	2.0	65°	22.5	44.8	2.0
7	70°	19.2	-	—	70°	25.1	51.0	2.0	70°	23.4	48.9	2.1
8	70°	23.0	-	—	70°	26.8	56.6	2.1	75°	28.2	54.5	1.9
9	65°	24.6	55.0	2.2	75°	28.8	60.6	2.1	70°	28.4	62.0	2.2
10	70°	27.0	66.0	2.4	75°	30.5	72.1	2.4	75°	28.4	61.5	2.2
11	70°	27.0	60.5	2.2	75°	27.4	69.4	2.6	75°	24.6	58.7	2.4
12	70°	26.4	62.5	2.3	75°	27.0	63.0	2.3	70°	26.4	62.7	2.4
13	75°	27.5	62.5	2.3	70°	26.1	61.0	2.3	75°	25.7	57.4	2.2
14	70°	21.9	56.7	2.5	70°	22.3	55.7	2.5	70°	23.0	52.0	2.3
15	65°	23.8	55.1	2.3	65°	20.9	50.0	2.4	75°	17.5	40.3	2.3
16	70°	18.2	43.2	2.3	70°	13.7	40.5	2.9	70°	10.7	33.8	3.2
17	—	5.6	26.4	4.7	—	7.3	16.7	2.3	—	6.2	29.7	4.8
18	remainder not measured.				remainder not measured.				remainder not measured.			
						Type 38.						
	Plant 1.				Plant 2.				Plant 3.			
1	Damaged				Damaged				Damaged			
2	,,				,,				,,			
3	,,				,,				,,			
4	,,				,,				,,			
5	,,				,,				,,			
6	,,				65°	31.6	43.0	1.4	65°	24.7	35.5	1.4
7	,,				65°	32.0	42.8	1.3	60°	28.4	43.3	1.5
8	65°	25.7	33.2	1.3	65°	35.3	52.3	1.5	65°	32.6	48.3	1.5
9	60°	24.5	37.5	1.5	65°	40.7	59.5	1.5	60°	36.4	55.1	1.5
10	65°	33.3	45.8	1.4	60°	33.6	56.1	1.7	65°	33.6	56.0	1.7
11	65°	35.4	52.5	1.5	65°	38.7	62.1	1.6	65°	38.1	58.8	1.5
12	60°	32.0	52.0	1.6	65°	39.7	63.2	1.6	65°	36.5	63.7	1.7
13	65°	35.5	55.2	1.6	65°	31.3	56.1	1.8	65°	33.2	57.9	1.7
14	60°	36.0	60.8	1.7	65°	38.6	63.0	1.6	65°	39.1	66.2	1.7
15	65°	34.0	57.6	1.7	65°	29.1	51.7	1.8	60°	31.2	58.5	1.9
16	65°	35.5	58.6	1.7	65°	31.5	55.8	1.8	65°	34.5	60.8	1.8
17	60°	27.4	52.0	1.9	60°	38.3	65.0	1.7	60°	37.4	59.5	1.6
18	65°	29.8	50.5	1.7	65°	28.6	49.9	1.7	60°	29.6	51.0	1.7
19	60°	34.2	56.0	1.6	65°	34.5	55.6	1.6	60°	35.3	56.4	1.6
20	60°	30.0	52.2	1.7	65°	32.3	52.4	1.6	65°	32.5	49.8	1.5
21	60°	25.2	47.1	1.9	65°	27.0	44.2	1.6	60°	31.2	51.2	1.6
22	65°	27.7	46.6	1.7	60°	30.2	48.4	1.6	65°	30.7	48.2	1.6
23	60°	27.0	45.1	1.7	65°	23.7	39.8	1.7	65°	23.3	38.0	1.6
24	60°	24.4	43.8	1.8	65°	18.8	33.6	1.8	60°	23.3	39.5	1.7
25	60°	19.7	36.6	1.9	60°	25.2	42.3	1.7	60°	20.8	32.3	1.6
26	60°	18.3	33.2	1.8	60°	16.4	28.1	1.7	65°	14.9	23.5	1.6
27	60°	20.3	34.5	1.7	65°	15.2	25.4	1.7	60°	14.1	22.6	1.6
28	65°	15.9	27.2	1.7	60°	10.3	18.6	1.8	remainder not measured.			
29	65°	12.5	20.0	1.6	remainder not measured.							
30	60°	9.5	16.7	1.8								
31	remainder not measured.											

for measurement and in many types the change between these and the significant leaves is very gradual. It is probable that in America the general uniformity of the kinds grown makes this method more applicable.

The actual procedure adopted in these investigations was as follows. Very small cardboard labels were prepared with the number of the plant and culture, and these were threaded with fine copper wire. These labels could be readily affixed to the leaf by passing the ends of the copper wire through the mid-rib, and bending them flat on the under side. The individual leaf chosen by the investigator for measurement was immediately labelled in this manner while on the plant. The leaves could then be removed and measured in some convenient place. The leaf after measurement was pressed with the label still attached, and thus a complete record of all the plants examined has been preserved. It is hoped to use this material in disentangling the factors which are concerned in the shape of the leaf. This method of attaching a label, which lies flat on the mid-rib, and therefore interferes with no measurement of the leaf while still on the plant, has proved most useful. The labour of preparing these labels, threading the wire, and the subsequent drying of the leaves, however, would not be possible for several thousand plants except for the cheap labour available in India. A second and a third leaf can be removed immediately above or below the first one chosen.

The venation of the leaves was determined by measuring the angle between the mid-rib and the lateral vein with a horn protractor. Only differences of 5° were noted. Experience showed that such determinations gave good results, and that the error generally was not more than ±5°. These measurements were carried out in two ways, either while the leaf was still attached to the plant or on the detached leaf which had been selected for other measurements. The first method has the advantage that all the leaves can be examined in a general manner by eye at the same time as the measurements are made ;

the second, that all the measurements such as width, length and venation are made on the same leaf. Comparative determinations on the same cultures by both methods give similar results. In most cases in 1913, the data given are the mean of two determinations, but experience shows that where time is limited one careful determination is quite sufficient. The difference between the determinations was not greater than the error of measurement.

The angle of venation appears to be extraordinarily constant for any one type (see Table XVII) and to be largely independent of the shape and width of the leaf. This is shown very well by Type 9, in which the angle remains constant at 50°, while the shape and width of the leaves varies greatly. An examination of Table XX shows that the angle of venation in the Indian types varies from 35° to 90° and that all the intermediate grades occur. The smallest angle, 35°, is found on a comparatively broad leaf. In Table XXI the relation between the venation and the shape of the leaf as expressed by the ratio length/breadth of the leaf is shown for the F_2 generation of Type 16 and Type 35, and also for all the Indian types on

TABLE XX.

Venation and ratio $\frac{\text{length}}{\text{breadth}}$ of the leaf in the various types of *N. tabacum*.

[illegible]nation.		Length. / Breadth.
[illegible]°	Type 19	2.4
[illegible]°	,, 7	4.1
	,, 8	4.4
	,, 10	4.1
	,, 11	3.5
	,, 12	3.3
	,, 13	3.0
	,, 14	3.8
	,, 20	2.6
	,, 21	2.8
[illegible]°	,, 22	2.3

Venation.		Length. / Breadth.
50°	Type 6	4.1
	,, 9	3.6
	,, 16	4.1
	,, 18	3.0
	,, 27	2.6
55°	,, 25	2.8
60°	,, 17	2.8
	,, 26	2.4
	,, 30	2.4
	,, 31	2.1
	,, 36	2.0
	,, 46	2.6

Venation.		Length. / Breadth.
60–65°	Type 38	1.7
65°	,, 33	1.9
70°	,, 24	2.6
	,, 34	2.2
	,, 39	1.9
	,, 40	2.1
	,, 42	2.1
	,, 43	2.2
	,, 44	2.2
	,, 45	2.2
	,, 38	1.8

Venation.		Len[illegible] / Brea[illegible]
75°	Type 23	2.[illegible]
	,, 37	2.[illegible]
	,, 41	2.[illegible]
	,, 30	2.[illegible]
80°	,, 35	1.[illegible]
	,, 47	1.[illegible]
	,, 48	1.[illegible]
	,, 51	1.[illegible]
90°	,, 50	1.[illegible]

TABLE XXI.

Venation and ratio $\frac{\text{length}}{\text{breadth}}$ in F_2 Type 16 × Type 35.

Ratio $\frac{\text{length}}{\text{breadth}}$	Size of Angle.											No. of Plants.
	40°	45°	50°	55°	60°	65°	70°	75°	80°	85°	90°	
1.7	—	—	—	—	—	1	—	—	1	—	—	2
1.8	—	—	—	—	—	1	—	1	1	—	1	4
1.9	—	—	—	—	—	6	—	3	4	2	1	16
2.0	—	—	—	—	4	3	7	6	12	4	1	37
2.1	—	1	—	2	9	8	5	5	4	7	1	42
2.2	—	1	5	4	7	6	19	9	8	1	1	61
2.3	—	1	2	3	13	8	8	3	4	—	—	42
2.4	—	—	4	8	26	7	13	6	4	—	—	68
2.5	—	1	4	11	10	5	9	3	2	—	—	45
2.6	1	1	8	7	9	7	2	1	—	—	—	36
2.7	—	2	6	2	4	5	4	—	1	—	—	24
2.8	—	1	10	4	5	3	1	1	1	—	—	26
2.9	—	—	1	1	2	3	—	—	1	—	—	8
3.0	—	2	3	—	4	1	—	—	—	—	—	10
3.1	—	2	3	1	2	1	1	—	—	—	—	10
3.2	—	1	3	—	1	—	—	—	—	—	—	5
3.3	—	—	3	2	—	—	—	—	—	—	—	5
3.4	—	—	1	1	—	—	—	—	—	—	—	2
3.5	—	—	—	1	1	—	—	—	—	—	—	2
3.6	—	—	—	1	—	—	—	—	—	—	—	1
3.7	—	—	—	—	—	—	—	—	—	—	—	—
3.8	—	—	—	—	—	—	—	—	—	—	—	—
3.9	—	—	—	—	—	—	—	—	—	—	—	—
4.0	—	—	—	—	—	—	—	—	—	—	—	—
4.1	—	—	1	—	—	—	—	—	—	—	—	1
Total	1	13	54	48	97	65	69	38	43	14	5	447

Table XX. It will be seen that there is no true correlation between these two characters, and this is confirmed by many of the F_3 cultures in which the venation was constant, but the shape of the leaf very variable—culture 202 and many others. There does, however, seem to be a limit to the occurrence of the higher angles. Those above 75° are only met with in leaves with small ratios. A more detailed examination of the venation affords a possible explanation of this, for that there is no *incompatibility between a large angle and a small ratio*, is shown by the banana leaf. There is a striking difference in the leaves of the tobacco between the behaviour of the lateral veins which arise at an acute angle and those in which the angle is large. The

former always go straight to the margin, which they naturally meet obliquely, while the latter curve at this point and run almost parallel to the margin. This may be to avoid rupture of the lamina, or it may enable the food channels to serve a larger portion of the leaf for in the case of the acute-angled venation the veins cover a long distance, while when the angle is 90° the distance is very short. If the leaf is broad, this curving upwards of the ends of the veins does not affect the angle near the mid-rib but if the leaf is narrow the latter would be reduced. This may

TABLE XXII.

Venation in Type 9 × Type 51.

	Venation of Parent.	40°	45°	50°	55°	60°	65°	70°	75°	80°	85°	90°	Total No. of Plants.
Type 9 1912		1	27	26	—	—	—	—	—	—	—	—	54
Type 9 1913		1	9	16	—	—	—	—	—	—	—	—	26
Type 51 1912		—	—	—	—	—	—	—	5	23	20	3	51
Type 51 1913		—	—	—	—	—	—	—	14	18	—	—	32
F_1 Type 9 × Type 51 1912		—	—	—	19	47	11	—	—	—	—	—	77
F_2 Type 9 × Type 51 1911		19	12	147	30	200	21	89	29	42	12	7	608
Type 9 × F_1 Type 9 × Type 51 1911		38	—	173	2	55	—	1	—	—	—	-	269
Type 51 × F_1 Type 9 × Type 51 1911		1	—	22	5	51	—	37	4	49	—	38	207
F_3 Type 9 × Type 51													
738—1912	50°	1	9	48	35	39	7	4	—	—	—	—	143
745—1912	50°	1	17	58	40	22	1	—	—	—	—	—	139
736—1912	60°	1	2	8	38	36	31	11	—	—	—	—	127
737—1912	60°	9	17	81	27	17	0	1	—	—	—	—	160
740—1912	70°	—	—	7	18	41	41	22	—	—	—	—	129
694—1912	75°	—	—	—	1	7	13	35	25	15	4	—	100
132—1912	80°	—	—	—	—	1	—	10	31	39	21	14	116
167—1912	80-85°	—	—	—	—	—	—	—	1	18	46	33	98
F_4 Type 9 × Type 51													
738-19—1913	40°	11	78	16	—	—	—	—	—	—	—	—	105
738-96—1913	50°	22	40	4	—	—	—	—	—	—	—	—	66
738-58—1913	50°	—	—	1	15	80	11	—	—	—	—	—	107
738-15—1913	55°	1	7	38	22	27	5	1	—	—	—	—	101
738-76—1913	60°	—	2	13	27	45	8	7	—	—	—	—	102
738-81—1913	70°	—	—	—	1	85	44	4	—	—	—	—	134
694- 1—1913	70°	—	—	—	—	1	41	40	21	—	—	—	103
694-38—1913	70°	—	—	—	—	—	—	10	45	32	20	—	107
694-23—1913	75°	—	—	—	—	—	—	4	32	16	3	—	55
694-103—1913	80°	—	—	—	1	8	15	26	27	20	2	—	99
694-10—1913	80°	—	—	—	—	—	—	15	37	35	15	—	102

explain why there is a limiting effect without true correlation.

The study of the venation has yielded some most interesting results and has demonstrated very conclusively the existence of homozygotic combinations with values between those of the parents. Table XXII gives the results of the cross Type 9 × Type 51. The F_1 is intermediate as usual, and the F_2 covers the combined range of the parents. In the F_3 only one culture, 167, appeared to be uniform, and this had a mean venation slightly greater than Type 51. The limits of variation were, however, very different in the various cultures, and two cultures in which these overlap very slightly, 738 and 694, were continued. From culture 738, with a range of 40° to 70° in the F_3, the plants with the lowest and highest angles were grown in the following year, as well as four others. In the F_4 generation two cultures 19 and 96 were uniform with an average venation of 50°, and a range of 40° to 55°, two others 58 and 81 were uniform with an average of 60°, while one culture 15 resembled the parent culture 738 in every respect. The behaviour of the other culture is not very clear; it may indicate another homozygotic combination at 55°. Thus two homozygotic combinations, representing 50° and 60° respectively, have been isolated, one of which is a replica of one of the parents, the other is new. The F_4 cultures of 694 do not give such definite information, but they indicate the occurrence of another homozygotic combination 65°-70°, and it is possible that 694-1 represents this.

The cross between Type 16 × Type 35 (Table XXIII) gives very similar results to those described before. All the cultures (four) with a venation of 50° or 45° have bred true; one culture of which the parent plant had a venation of 60° has also bred true, and here again is the formation of a homozygotic combination intermediate between the two parents. Cultures 200 and 8 are possibly uniform with an average of 75°, again a *novum*. The other cultures are apparently heterozygotes splitting within different limits.

Table XXIII.

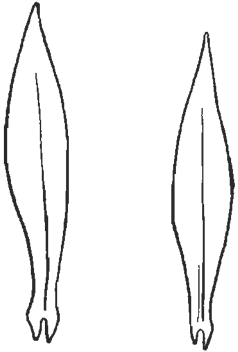
Venation in Type 16 × Type 35.

	Venation of Parent.	40°	45°	50°	55°	60°	65°	70°	75°	80°	85°	90°	Total No. of Plants.
Type 16 1912		—	13	49	11	—	—	—	—	—	—	—	73
Type 16 1913		—	—	22	10	1	—	—	—	—	—	—	33
Type 35 1912		—	—	—	—	—	—	3	10	52	9	—	74
Type 35 1913		—	—	—	—	—	—	—	13	19	2	—	34
F_1 Type 16 × Type 35 1912		—	—	—	—	7	28	—	—	—	—	—	35
F_2 Type 16 × Type 35 1912		—	6	32	29	58	43	41	25	20	7	1	262
F_2 Type 16 × Type 35													
27—1913	45°	—	17	78	14	1	—	—	—	—	—	—	110
202—1913	50°	—	22	73	9	3	—	—	—	—	—	—	107
190—1913	50°	—	21	67	21	—	—	—	—	—	—	—	109
231—1913	50°	2	23	65	14	—	—	—	—	—	—	—	104
251—1913	55°	1	9	38	39	17	3	—	—	—	—	—	107
142—1913	55°	—	8	38	40	20	2	—	—	—	—	—	108
163—1913	60°	—	—	—	—	—	18	67	16	—	—	—	101
15—1913	70°	—	2	*6*	*18*	*24*	*30*	*18*	*6*	*1*	—	—	105
35—1913	75°	—	—	1	5	8	12	15	32	16	5	—	94
9—1913	80°	—	—	—	—	4	6	42	41	14	—	—	107
200—1913	80°	—	—	—	—	—	—	19	49	34	3	—	105
8—1913	85°	—	—	—	—	—	—	7	56	35	7	—	105

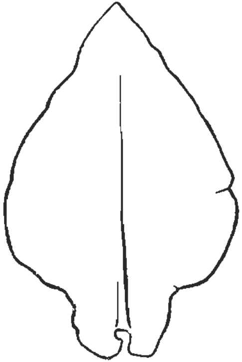
Table XXIV.

Venation in Type 23 × Type 38.

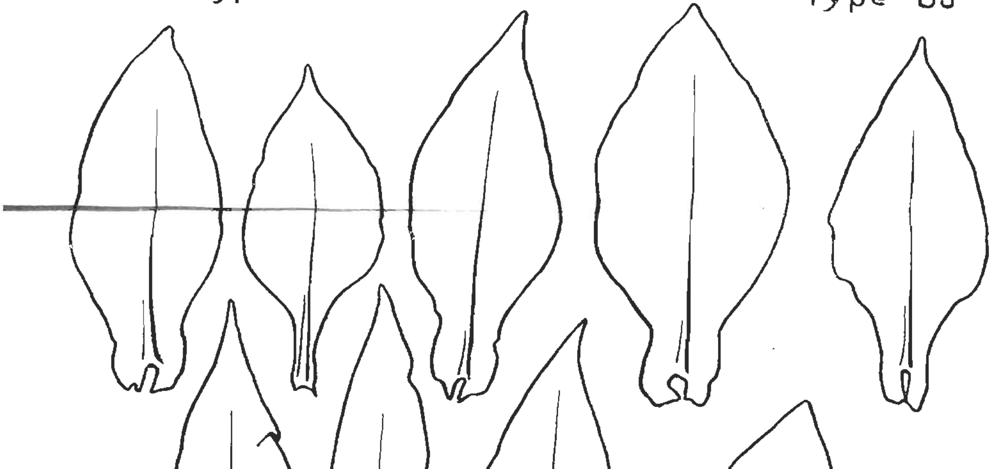
	Venation of the Parent.	40°	50°	55°	60°	65°	70°	75°	80°	85°	90°	Total No. of Plants.
Type 23 1912		—	—	—	—	—	33	38	2	—	—	73
Type 23 1913		—	—	—	—	—	12	14	—	—	—	26
Type 38 1912		—	—	—	7	28	23	3	—	—	—	61
Type 38 1913		—	—	—	7	22	11	—	—	—	—	40
F_1 Type 23 × Type 38 1913		—	—	—	—	1	13	35	—	—	—	49
F_2 Type 23 × Type 38 1912		—	—	—	4	10	46	34	5	1	—	100
F_3 Type 23 × Type 38												
213—1913		—	—	—	38	52	13	—	—	—	—	103
6—1913	*75°*	—	—	—	—	—	*24*	*69*	*11*	—	—	*104*
155—1913		—	—	—	1	13	62	15	—	—	—	91
159—1913		—	—	—	12	32	38	23	—	—	—	105
104—1913	70°	—	—	—	—	1	55	39	50	1	—	146
111—1913		*Like F_2 60°–80°*										
204—1913		,, 60°–80°										

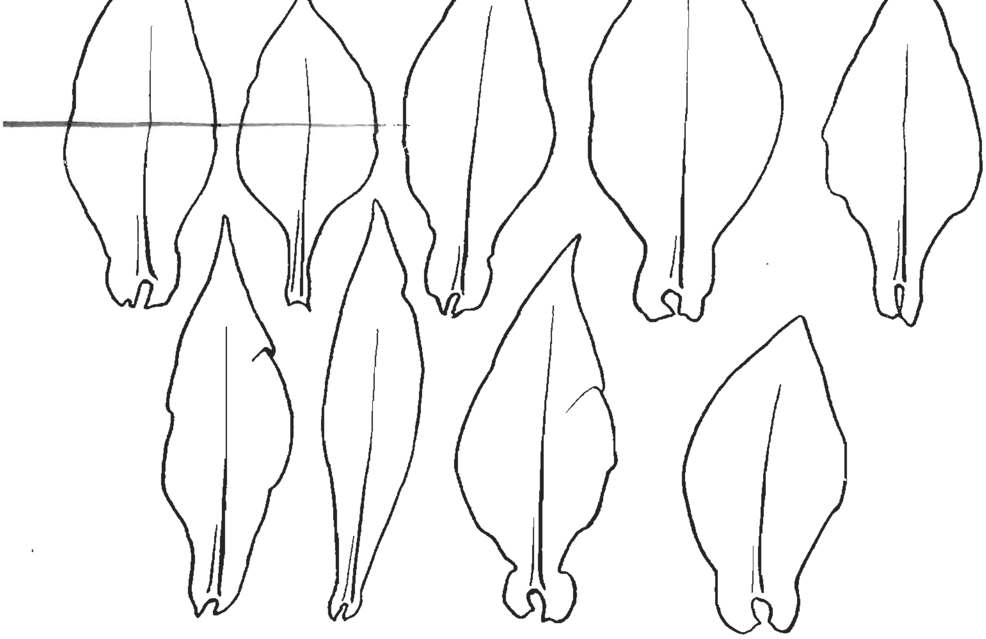


Type -16



Type - 35





F_2 Generation

FORMS OF LEAVES IN F_2 TYPE 16 · TYPE 35.

As the parents in the cross Type 23 × Type 38 (Table XXIV) are so similar as regards venation, no investigations on this character were contemplated. A few measurements were made, however, in the F_2 as some other characters had given curious results in this generation. The results obtained in this generation afforded very striking evidence of the accuracy of the method adopted, and so a few cultures were measured in the F_3. Type 23 has a range of 70° to 80°, Type 38 of 60° to 75°, both therefore overlap. The plants in the F_2 generation had a range of 60° to 85°, the combined range of the parents. In the F_3, cultures were found like both parents, i.e., Nos. 213 and 6, some like the F_2, Nos. 111 and 204 and others, which indicate the possibility of another homozygotic combination with an average of 70°.

7. THE LEAF SHAPE.

The most difficult characters to investigate are those connected with the shape of the leaf. The large number of forms, all slightly different, with apparently endless modifications of the individual parts, appear at first to defy analysis. A detailed study of the existing forms and their behaviour on hybridization shows that the number of characters is not so great as might be supposed, although the factors composing such characters are probably numerous. The form of a tobacco leaf can be expressed by a determination of the following points: (1) ratio length/breadth, (2) position of the greatest width, (3) amount of indentation at the apex, (4) amount of indentation at the base, (5) shape at the point of insertion, that is, whether auriculate or not. According to the evidence which has accumulated during these investigations all these characters are inherited quite independently of one another.

The influence of the ratio length/breadth on the shape of the leaf is obvious. The ratio depends on the two variable characters, length and breadth. Apart from environmental

influence, the width of the leaf is not dependent on the length. The Indian types of tobacco, with their great diversity of leaf shape, illustrate this point well. In countries with a high level of agriculture, economic considerations have eliminated all varieties except those possessing a certain type of leaf, a broad leaf with a large surface. In India, on the other hand, where the conditions of seed selection are primitive, and where thickness of leaf is desired for certain purposes, the cultivation of forms with very narrow leaves has persisted. Type 9 (Plates I and XVIII) is a very good example of a long narrow leaf and in Types 16 and 35 we have two leaves similar in length (average length, 42.9 cm. and 46.6 cm. respectively) with a very great difference in the

Ratio L…/Br…

	Ratio of Parent.	1.4	1.5	1.6	1.7	1.8	1.9	2.0	2.1	2.2	2.3	2.4	2.5	2.
Type 51 1912		—	—	—	1	7	21	11	3	—	—	—	—	—
Type 51 1913		—	—	—	—	6	6	10	9	1	—	—	—	—
F_1 Type 9 × Type 51 1912		—	—	—	—	—	—	—	—	4	6	8	7	8
F_3 Type 9 × Type 51														
167—1912		—	—	2	9	10	26	15	21	8	1	1	—	—
132—1912		—	—	—	2	7	21	29	26	14	5	2	2	—
694—1912		—	—	—	1	4	18	19	20	13	10	5	3	1
737—1912		—	—	—	—	—	—	—	1	3	3	6	7	10
738—1912		—	—	—	—	—	—	—	—	1	4	6	10	10
745—1912		—	—	—	—	—	—	—	—	1	—	3	4	2
736—1912		—	—	—	—	—	—	—	—	—	1	4	7	5
740—1912		—	—	—	—	—	—	—	—	—	—	2	3	6
F_4 Type 9 × Type 51														
738- 81—1913	2.7	—	—	—	—	—	—	—	—	—	—	3	5	4
738- 15—1913	2.9	—	—	—	—	—	—	—	—	—	—	1	8	9
738- 58—1913	3.2	—	—	—	—	—	—	—	—	—	—	—	—	—
738- 76—1913	3.2	—	—	—	—	—	—	—	—	—	—	5	5	11
738- 19—1913	3.3	—	—	—	—	—	—	—	—	—	—	—	—	2
738- 96—1913	3.8	—	—	—	—	—	—	—	—	—	—	—	—	—
694- 23—1913	1.9	—	2	1	8	19	18	4	1	2	—	—	—	—
694- 1—1913	2.1	—	—	—	—	—	—	3	5	22	28	19	19	6
694-103—1913	2.2	—	1	1	8	17	14	27	7	10	8	6	1	—
694- 38—1913	2.2	—	—	—	2	16	21	27	27	12	2	—	—	1
694- 10—1913	2.2	—	1	—	1	8	14	26	32	15	5	—	—	—

width (average width 11.1 cm. and 29.2 cm. respectively). On Plate XIX are shown some of the leaves of the F_2 generation of this cross, drawn to scale.

All the evidence accumulated during these investigations tends to show that differences in width can be inherited quite independently of the length. The very great effect of fluctuating and temporary changes in environment on the size of the leaves makes a thorough study of the inheritance of the width or of the length difficult and necessitates a large number of measurements. Time has not permitted me to measure sufficient leaves per plant to make any very definite statements as regards the factors composing these characters. As regards

Type 51.

1	3.2	3.3	3.4	3.5	3.6	3.7	3.8	3.9	4.0	4.1	4.2	4.3	4.4	4.5	4.6	4.7	4.8	4.9	5.0	Total No. of
–	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	4
–	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	3
1	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	4
–	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	9
–	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	10
–	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	9
2	9	4	9	4	2	2	—	2	1	2	1	1	—	—	1	—	1	—	—	12
9	10	6	5	4	4	3	4	—	—	—	1	—	—	—	1	—	—	—	—	13
4	16	13	8	5	9	7	4	3	5	2	1	2	1	1	2	—	—	—	2	14
4	6	9	4	7	3	4	4	1	1	—	—	—	1	—	—	—	—	—	—	12
8	9	10	4	2	1	—	—	—	—	—	—	—	—	—	—	—	—	—	—	12
7	9	6	3	4	2	2	2	—	—	—	—	—	—	—	—	—	—	—	—	11
5	5	1	3	1	3	1	—	—	—	—	—	—	—	—	—	—	—	—	—	9
9	9	9	12	11	4	5	4	3	1	1	—	—	—	—	—	—	—	—	—	10
4	5	6	2	—	—	1	1	—	—	—	—	—	1	—	—	—	—	—	—	8
5	14	10	10	8	6	4	1	3	2	—	—	—	—	—	—	—	—	—	—	9
7	13	7	6	7	1	3	2	1	—	—	—	—	—	—	—	—	—	—	—	6
–	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	5
–	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	10
–	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	10
–	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	10
–	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	10

Ratio Le[illegible] / Bre[illegible]

	Ratio of Parent.	1.4	1.5	1.6	1.7	1.8	1.9	2.0	2.1	2.2	2.3	2.4
Type 35 1912		6	21	18	6	—	—	—	—	—	—	—
Type 35 1913		—	11	18	8	—	—	—	—	—	—	—
Type 16 1912		—	—	—	—	—	—	—	—	—	—	—
Type 16 1913		—	—	—	—	—	—	—	—	—	—	—
F_1 *Type 16* × *Type 35* 1913		—	—	—	—	—	—	—	1	3	6	20
F_2 Type 16 × Type 35 1912		—	—	—	2	4	16	37	42	61	42	68
F_3 Type 16 × Type 35												
9—1913	1.9	—	—	—	—	2	7	14	23	31	16	10
8—1913	2.0	—	—	—	—	—	5	19	33	27	13	4
200—1913	2.1	—	—	—	2	13	13	27	20	12	10	5
231—1913	2.1	—	—	—	—	—	—	—	—	—	4	3
202—1913	2.1	—	—	—	—	—	—	—	—	—	—	—
35—1913	2.2	—	—	—	—	—	6	17	16	13	14	19
15—1913	2.3	—	—	—	—	—	—	3	7	12	14	20
163—1913	2.3	—	—	—	—	—	—	1	—	3	11	29
251—1913	2.5	—	—	—	—	—	—	—	3	8	17	16
142—1913	2.7	—	—	—	—	—	—	1	2	15	16	22
190—1913	—	—	—	—	—	—	—	—	—	—	—	1
27—1913	—	—	—	—	—	—	—	—	—	1	1	3

Ratio [illegible]

	Ratio of Parent.	1.4	1.5	1.6	1.7	1.8	1.9	2.0	2.1	2.2	2.3	2.4
Type 23 1912		—	—	—	—	—	—	1	—	2	6	21
Type 23 1913		—	—	—	—	—	—	2	2	8	4	6
Type 38 1912		—	—	2	14	10	10	4	2	—	—	—
Type 38 1913		—	—	4	4	10	3	2	1	—	—	—
F_1 Type 23 × Type 38 1913		—	1	3	9	22	8	4	—	1	—	—
F_2 Type 23 × Type 38 1912		3	2	6	18	27	37	54	62	50	32	20
F_3 Type 23 × Type 38												
104—1913	1.6	4	14	30	31	12	6	—	—	—	—	—
6—1913	1.9	—	2	11	13	26	16	13	11	2	2	1
117—1913	2.0	—	2	7	12	11	12	9	12	6	1	—
204—1913	2.0	—	—	3	5	17	22	16	17	11	6	2
159—1913	2.0	—	—	—	4	12	23	12	24	11	8	4
111—1913	2.1	—	3	2	11	6	21	20	13	14	3	1
213—1913	2.2	—	2	2	15	18	23	19	12	7	3	1
155—1913	2.4	—	—	—	3	10	16	25	18	19	5	3
9—1913	—	1	11	16	26	18	18	4	1	3	1	—

XXVI.

Type 16 × Type 35.

2.7	2.8	2.9	3.0	3.1	3.2	3.3	3.4	3.5	3.6	3.7	3.8	3.9	4.0	4.1	4.2	4.3	4.4	4.5	Total No. of Plants.
—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	51
—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	37
—	—	—	—	—	—	—	—	2	—	3	7	7	8	3	6	5	2	2	45
—	—	—	—	—	—	—	—	—	5	5	1	8	9	5	3	1	—	—	37
4	2	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	62
24	26	8	10	10	4	5	2	2	1	—	—	—	—	1	—	—	—	—	446
1	1	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	108
—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	104
—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	102
16	13	10	8	9	6	1	2	—	1	1	—	—	—	—	—	—	—	—	104
12	22	17	8	7	9	2	2	—	—	—	2	—	—	—	—	—	—	—	94
4	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	103
7	9	6	1	2	2	1	1	1	—	—	—	—	—	—	—	—	—	—	109
9	10	2	2	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	101
10	9	2	2	1	—	—	—	—	—	—	—	—	—	—	—	—	—	—	108
6	7	1	1	1	—	—	—	—	—	—	—	—	—	—	—	—	—	—	107
3	10	15	14	20	16	6	3	7	6	—	2	—	1	1	—	—	—	—	108
7	14	13	6	15	13	5	2	4	5	1	4	1	2	1	1	—	—	—	105

XXVII.

Type 23 × Type 38.

2.7	2.8	2.9	3.0	3.1	3.2	3.3	3.4	3.5	3.6	3.7	3.8	3.9	4.0	4.1	4.2	4.3	4.4	4.5	Total No. of Plants
4	2	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	63
—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	25
—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	42
—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	24
—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	48
2	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	335
—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	97
—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	98
—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	72
—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	100
—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	104
—	1	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	98
—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	103
—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	103
—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	99

the environmental influences, however, both the breadth and the length appear to be similarly affected, and the ratio between the two is therefore less dependent on these influences. The ratio length/breadth has been studied in three crosses (see Tables XXV, XXVI, and XXVII). The results are very much the same as in other characters. In Table XXV the ratio from Type 9 is not given, as it will be evident from Table XVI that no two leaves are alike in this respect. In Table XXIV the most interesting culture is 694 which, although almost uniform in the F_3 generation, has shown further segregation in the following year.

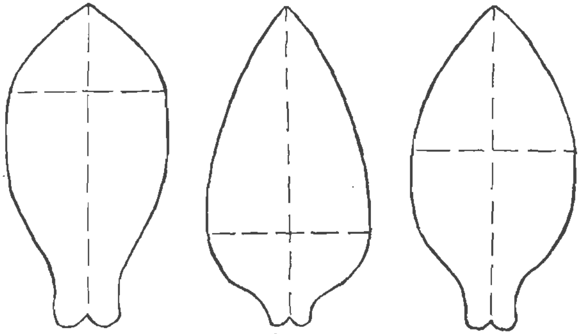


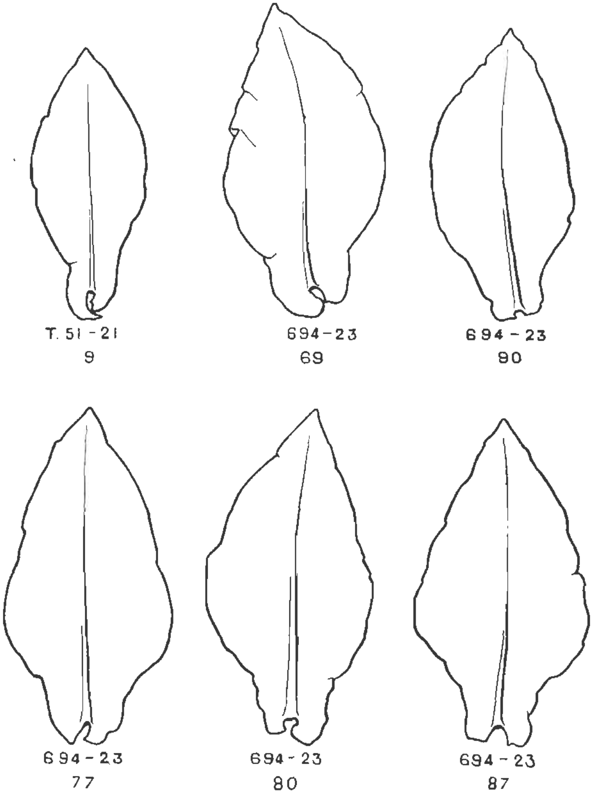
Fig. 1. Leaf shape and position of greatest width.

In cross Type 16 × Type 35 where the length of the leaves is approximately the same, but the width very different, the ratios formed by a combination of the length of one with the width of the other are the same as the original ratios. The data of the F_3 generation clearly point to the action of several factors in producing the difference between the widths of the two leaves.

The position of the greatest width is a very important point in dealing with the leaf shape. The above diagram shows how the appearance of the leaf can be entirely altered by varying the position of this point.

8.3	8.5	8.7	8.9	9.1	9.3	9.5	9.7	9.9	10.1	10.3	10.5	10·7	10·9	11.1	11.3	11.5	11.7	Total No. of Plants.
—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	45
—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	23
—	1	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	290
—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	22
—	1	—	—	1	—	—	—	1	—	—	—	—	—	—	—	—	—	23
—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	49
—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	189
—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	162
—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	104
—	1	1	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	103
—	—	1	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	91
—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	99
2	2	1	2	2	—	—	1	2	—	—	1	—	—	—	—	—	—	103
—	1	1	3	—	—	—	1	—	—	—	—	—	—	—	—	—	—	101
3	3	—	2	1	2	3	3	—	1	—	1	1	—	—	1	—	—	101

P



LEAVES OF T 51 AND OF CULTURE 694 (F_1 $T_9 \times T_{51}$).

In Type 51 the position of the greatest width has been determined for a large number of leaves, and is always half-way between the apex and the base. In Type 9 it is lower at a point two-fifths from the base of the leaf. Determinations of this point made in the F_3 generation on cultures derived from 694 showed that all were uniform in this respect and resembled Type 9 exactly, although in size and ratio length/breadth they were very like Type 51. On Plate XX some of these leaves are shown, contrasted with a leaf of Type 51. Apparently this character can be inherited quite independently of the ratio length/breadth and it is possible to combine in the same leaf the ratio length/breadth of one parent with the greatest width in the same position as in the other parent. Similarly, very distinct segregation as regards this character was observed in the cross Type 23 × Type 38. A large number of cultures have been measured with reference to this point, but as the number of tables is already great, the results will not be published until the fuller investigation of the factors concerned with the shape of the leaf is completed. The measurements were carried out by moving a steel measure at right angles up the leaf until it denoted the greatest width, when its position was marked by inserting a needle into the mid-rib. The distance between this point and the base of the leaf was then determined.

The ratio length/breadth and the position of the greatest width are sufficient to determine the general form of the leaf in all cases. If we further imagine pieces of varying size to be cut out at the apex and base of the leaf we are able to reproduce the leaves of all the existing types. If we postulate the existence of independent factors the effect of each of which is to cause a different indentation in the outline, all the facts which have been discovered during this investigation can be explained.

The most striking example is that given by the cross Type 23 × Type 38 (Table XXVIII). Both these forms have sessile leaves, but the amount of indentation near

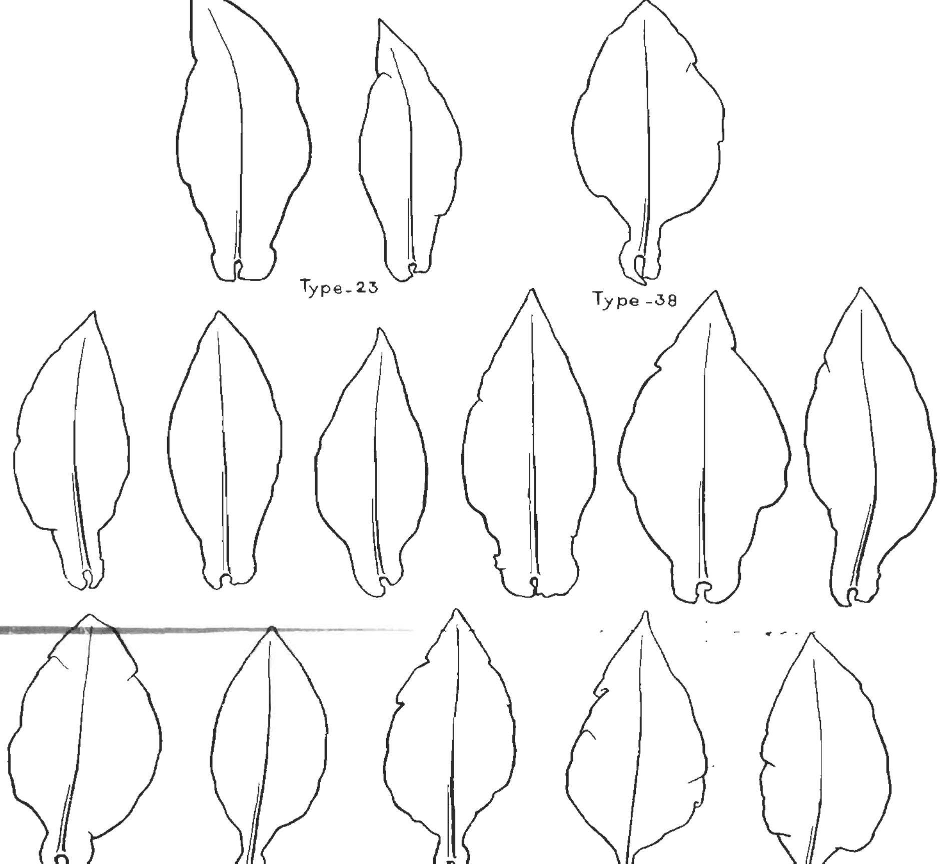
the base is different (see Plate XXI, in which both parents and typical leaves from the F_2 generation are shown). The measurements were obtained by measuring the lamina on either side of the mid-rib and obtaining the mean value. This is preferable to any measurement across the leaf as it eliminates the width of the mid-rib, which is probably an independently varying character. The outline of Type 23 is almost straight, while that of Type 38 is suddenly contracted. On hybridization, the F_1 has a bigger indentation than either parent. In the F_2, petiolate forms occur in which the amount of lamina on either side of the petiole is less than .3 cm. All stages between these and Type 23 were found. Nine cultures were carried on to the F_3. The petiolate forms, Nos. 117 and 213, bred true in the third generation. If the indentation in the parents be due to two different factors or combinations of factors, then the effect of their combined presence might be to reduce the lamina to a negligible amount. These forms possessing both factors would be homozygotic and breed true. Two cultures, Nos. 155 and 204, which in the F_2 possessed a small amount of lamina gave a progeny of petiolate and sessile forms which could be easily separated both by eye and by measurement into three distinct groups in the ratio 1 : 2 : 1. The actual numbers were as follows:—

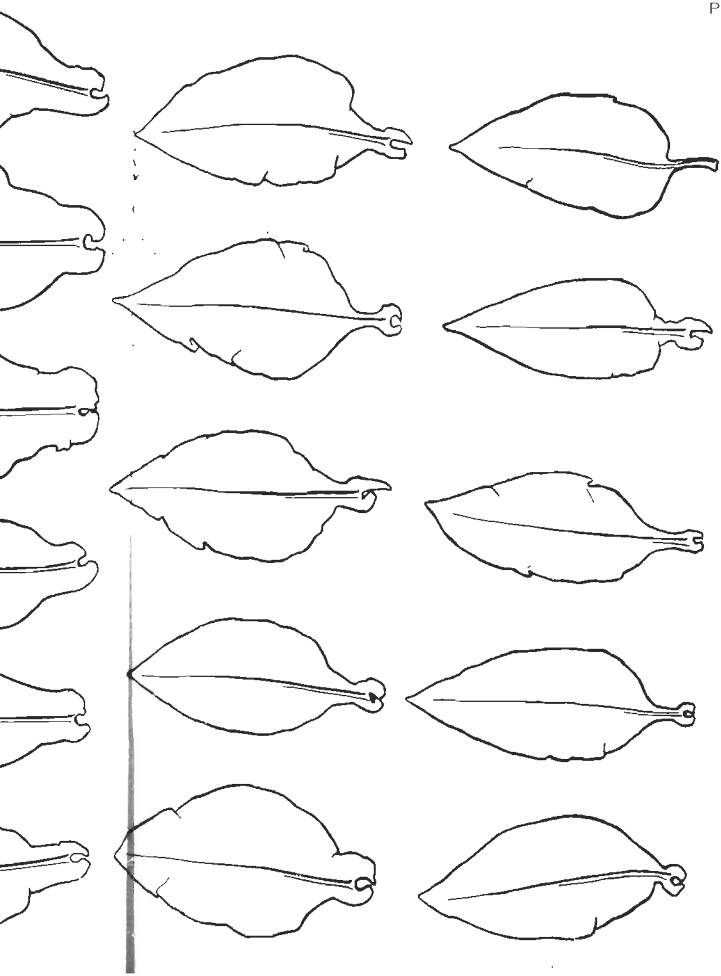
Culture 159—petiolate 25, intermediate 52, sessile 27.

Culture 204—petiolate 24, intermediate 48, sessile 33.

The parent plants were probably homozygotic for one factor and heterozygotic for the other.

Three other cultures gave progeny in which a certain number of petiolate forms occurred, but these formed a series with the sessile forms, and the number of such plants was much less than a quarter of the whole. In two cultures, Nos. 104 and 111, no petiolate forms at all occurred. If the presence of both indentations is possible, the absence of both must also be possible. Some leaves with an outline showing even less indentation than Type 23 were found, but the range of variation of the latter was, in 1913, so great that


Type-23
Type-38



F_2 Generation.

FORMS OF LEAVES IN F_1 TYPE 23 × TYPE 38.

this could not be confirmed by direct measurement. These cultures were very luxuriant and over-grew their normal limits. The question is complicated by the fact that the indentation of Type 38 is sudden and short, while it is gradual in Type 23. Indications of a segregation in this direction were also observed. These results indicate that the apparently stalked varieties of tobacco are not really petiolate, but sessile. This explains the alate nature of the petiole and the fact that in many such types the upper leaves are sessile, the lower petiolate.

Further evidence on this point was obtained from the other two crosses. Many cases in which the form of the lower part of the leaf varied, but the indentation factors did not differ so widely as in Type 23 and Type 38, were observed in the F_4 generation of the cross Type 9 × Type 51. No petiolate forms occurred, showing that the combined effect of the indentation factors was not great enough to remove all the lamina. Different ranges were shown by different cultures.

Observations in the field together with a comparison of Tables XXV, XXVI and XXVII, show that these indentation factors are inherited quite independently of the leaf ratio and also independently of the width of the leaf. Environmental influences would, however, by influencing the vigour of the plant, affect both alike.

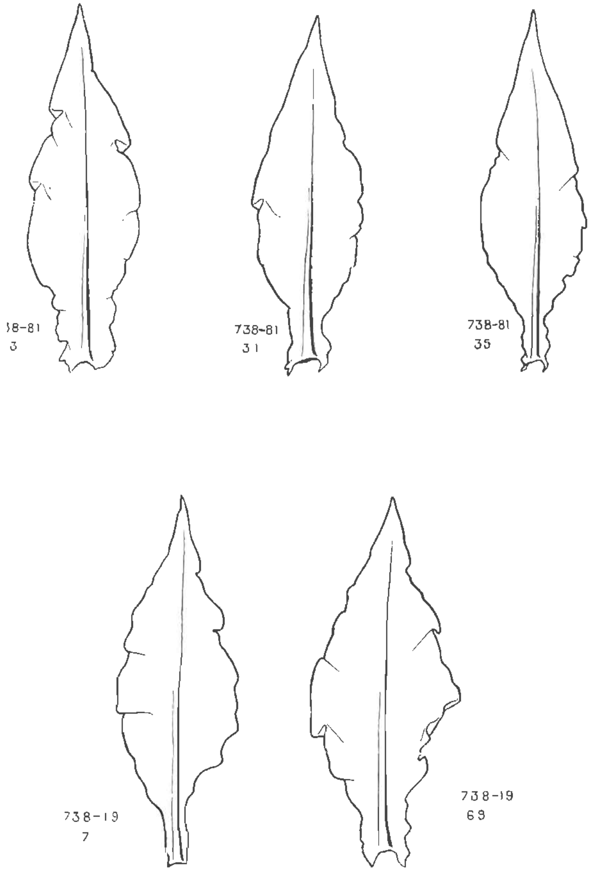
Plate XXII shows three leaves selected from culture 738-81, in which both width and length are the same but the amount of indentation at the base varies. On the same Plate are shown two leaves of 738-19, in which the length is the same, but the width and the form of the base vary. In some cultures the configuration of the base was uniform, such as 694-1. Plate XIX gives a very good indication of the range obtained as regards this character in the cross Type 16 × Type 35. The F_3 cultures showed very different limits of variability. In one case, culture 9, there was apparently only one heterozygotic factor, a separation by eye gave twenty-five plants with a similarly broad base in 108 plants.

A similar explanation to the series of independent indentation factors appears to hold good in the case of the leaf apex. A curious feature of the leaves in some of the Indian tobaccos is a *sudden constriction of the lamina near the apex of the leaf, which gives the appearance of a prolongation of the surface into a long slender tip; in others the tip is short.* Good examples of both these cases are seen in the F_2 generation of Type 16 × Type 35. (Plate XIX). At first sight it would appear as if this sudden constriction were absent in both parents but indications of it can be detected in the apex of Type 16, although the narrowness of the leaf has diminished its effect. Evidence as to the independence as regards inheritance of the factors concerned in the configuration of the apex is given in this Plate. Other examples are shown on Plate XXIII. In 738-81, Nos. 14 and 60, are shown two leaves with similar apices but dissimilar widths, in 738-15, Nos. 38 and 96, are shown two leaves with the same width, but dissimilar apices, while 738-19, Nos. 68, 47 and 23, show the two extreme forms of apex found in that culture with an intermediate form. All these drawings are to scale.

In three F_3 cultures of the cross Type 16 × Type 35, the leaves could be divided by eye as regards the configuration of the apex, into three different groups giving a ratio 1 : 2 : 1. This shows that the plant was heterozygotic as regards one apical factor only. Culture No. 9 gave 29 leaves with broad apices; 50 intermediate; 30 with pointed apices. Culture No. 35 gave 30 : 50 : 24. Culture 163 bred true as regards the apex. These three cultures are illustrated in Plate XXIV.

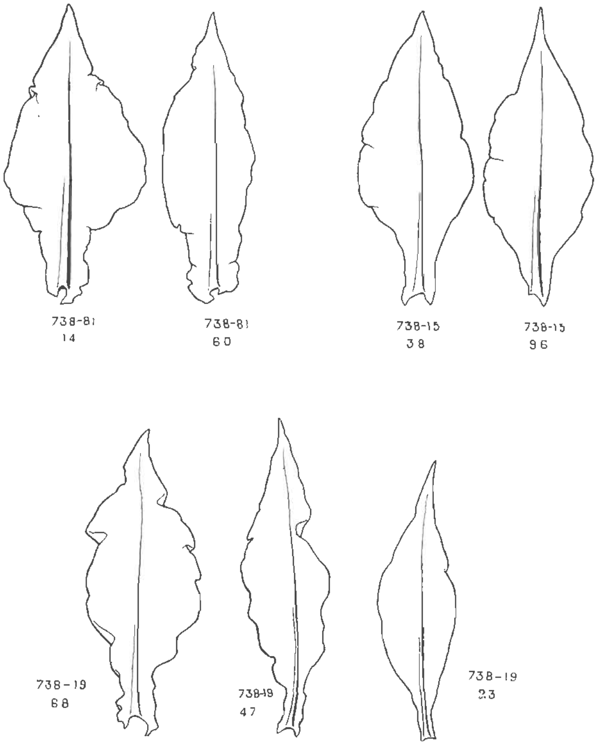
No information is as yet available as regards the inheritance of the presence and shape of auricles at the base of the leaf.

It is hoped to publish a further paper on the factors concerned in the leaf shape when the study of the pressed leaves has been completed, but enough evidence has been given in this section to show that the form of the leaf can be expressed by a knowledge of the ratio length/breadth, the position of greatest



RIOUS FORMS OF LEAVES IN CULTURE 738 (F_4 T_9 × T_{31}).

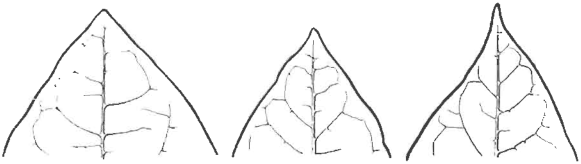
PLAT



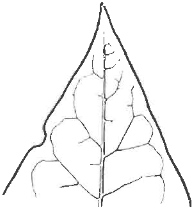
INDEPENDENCE OF WIDTH AND APEX.

PLATE

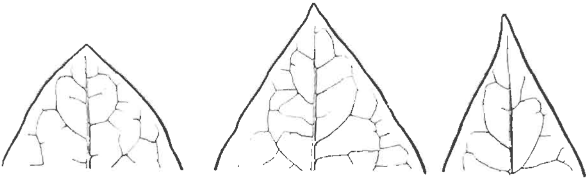
16×35 – 35



16 ×35 – 163



16×35 – 9



DIFFERENT FORMS OF APEX.

width, and the amount of indentation at the apex and base. All these characters vary independently of one another and can be inherited separately, and their mode of inheritance can be explained by the existence of independent interchangeable factors.

8. CHARACTER OF THE SURFACE AND THE MARGIN OF THE LEAF.

These characters are very difficult to investigate. In the first place, the nature of the irregularities in the surface may be different; in the second place, the various stages and combinations are very difficult to distinguish by eye; in the third place, even the so-called flat leaves have a certain amount of undulation at the base. From a study of the various Indian types, the following conditions appear to be the most frequent—large undulations of the whole leaf as in Type 9, large undulations confined to the base only, a general puckering of the surface between the veins and a small undulation or "frilling" of the edge. This frilling of the edge occurs in Type 51, but is best shown by the photograph of a plant which arose from the cross Type 9 × Type 51, namely, No. 694-23 in Plate XVI.

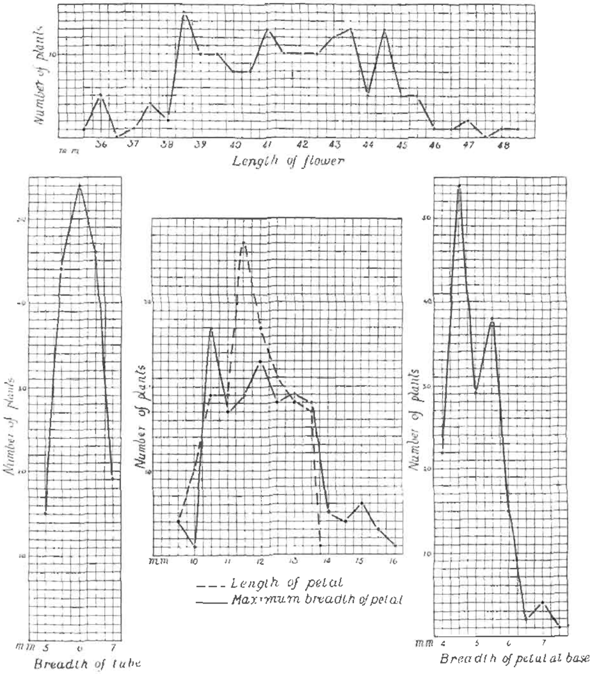
The investigations on this point have been confined to the cross Type 9 × Type 51. Type 9 has a leaf which is very undulate all over, while in Type 51 the edge is frilled but the surface is flat except at the extreme base, where an occasional slight undulation may occur. Taking the leaf surface only, it was found that the F_1 was intermediate and that the F_2 showed a series of forms intermediate between both parents, with a slight intensification, a few plants being more undulate than Type 9. Two hundred and fifty plants were examined by two observers. It was found possible to distinguish seventeen plants like Type 9, and three slightly more undulate. Fifty-seven plants were found with a slight undulation at the base or quite flat. These two classes could not be sub-divided. The

remainder could be classified as follows :—base slightly undulate, slightly undulate all over, undulate at the base only, undulate all over, very undulate all over, a little less undulate than Type 9,—showing that in all probability the undulation of the base is determined by a different factor to that of the general surface of the leaf. The numbers obtained indicate the existence of two factors and a ratio of 15 : 1, namely, 17 + 3 plants like Type 9 in 250 plants gives a ratio 11.5 : 1. It is, however, possible that the occasional undulation noticed at the base of Type 51 owes its existence to a third factor and that the plants that were even more undulate than Type 9 represent the combination of the factors involved in Type 9 plus this factor. The ratio 247 : 3 makes this appear possible. The seventeen plants like Type 9 would consist of the homozygotic combination Type 9, the heterozygotic intermediate between Type 9 and Type 9 intensified by the factor from Type 51. In a three factor combination tbe ratio of these to the total number of plants would be 3 : 64, i.e., there should be twelve plants, not seventeen. The number of plants examined is, however, two few to enable any definite conclusion to be drawn.

The "frilling" of the edge appears to be inherited independently of the surface undulations. This character cannot be observed when the general undulations of the leaf are great. In the present case this character was observed on fifty-seven plants. Of these, fifteen had no frilling at the edge, the others were frilled to a varying degree. This gives a ratio 42 : 15, or 2.8 : 1, so that here we are dealing with a simple factor. Some of these plants with flat leaves and frilled margins were carried on in the F_3 generation, and the following results were obtained :—

Culture 694—105 plants, 78 with frilled margins, 27 with flat margins.

Culture 167—99 plants, 73 with frilled magrins, 26 with flat margins.



COROLLA MEASUREMENTS. F_2 TYPE 9 × TYPE 51.

9. COROLLA.

As regards the corolla the following measurements were made on both parents, the F_1 and F_2 generations in the cross Type 9 × Type 51—length of the flower, length of the individual petal, maximum breadth of the petal, basal breadth of the petal, breadth of the corolla tube and breadth of the funnel. The results observed were similar to those obtained in the leaf characters. The intermediate nature of the F_1 was perfect even to the method of pollination. The F_2 generation gave a series covering the limits of both parents. The full data are not given here as they present no new features, but a graphic representation is given in Plate XXV. Want of time made further measurements in the F_3 and F_4 generations impossible.

The difference in the colour of the corolla in this case was probably due to two factors. The F_2 generation could be divided into more than three groups, and those classified as white formed one quarter of the whole, forty-five plants out of 117. The large number of gradations obtained in the F_2 generations indicate that this is probably not a simple 3 : 1 ratio, but that some of the palest pink combinations were indistinguishable from white.

V. CONCLUSIONS.

The results obtained in these investigations may be briefly summed up as follows :—

1. In any statistical investigation on the mode of inheritance, the uniformity of the environment in which each set of cultures is grown is exceedingly important. Comparisons should not be drawn between cultures unless they are grown close to one another with full precautions as to uniformity in environment. By careful attention to cultural details it is possible to reduce greatly the effect of environmental fluctuations. The importance of using in such investigations only normal, well grown plants cannot be over-estimated.

2. Parthenogenesis in *N. tabacum*, under the conditions obtaining in hybridization work at Pusa, is negligible.

3. In all characters except height, the F_1 generation is *intermediate between the parents. In the case of the height*, different results were obtained in different crosses. This may be due to added vigour in the hybrid plants. It is suggested that the differences in the increase produced by this may depend on differences in the number of dissimilar factors in the parents.

4. In all cases the limits of variation in the F_2 generation have been as great as those of both parents combined or have exceeded these in both directions. In some cases, where the parents and the F_1 generation were all alike, the variation in the F_2 was very great. This can readily be explained by the hypothesis that most of the factors possessed by the parents are different.

5. Selected variates of the F_2 generation gave cultures which differed in their range of variation from one another, and

often from the parents—the range of variation diminishing with further selection. Certain cultures showed so small a range of variation as to appear uniform; some of these resembled the parent forms, some were new.

6. Observations on the time of flowering during four generations resulted in the isolation of a culture flowering slightly earlier than one parent, and others flowering much later, together with some in which the range of variation was great.

7. It has been shown that although the heights of tobacco plants may only differ slightly, nevertheless the factors on which such heights depend may be almost all different. In one cross, a new form (probably uniform) much shorter than the shorter parent, has been isolated; in another cross, forms resembling both parents were obtained. If there is a basal condition of height common to all tobacco plants it must be small.

8. The number of leaves per plant does not depend on the height of the plant and is practically independent of the environment. The inheritance of this character can be explained by a basal condition (of not more than nineteen leaves) common to all types of *N. tabacum*, combined with independent factors which can add to this number. These factors are probably different in magnitude, that is, they represent an addition of different numbers of leaves.

9. Distinct segregation has been observed as regards the arrangement of the leaves on the stem. The arrangement with internodes of equal length invariably breeds true.

10. The length of the decurrent portion of the lamina is probably due to the existence of several factors. Hybridization between plants whose leaves are equally decurrent has produced forms with nondecurrent leaves. The differences in length due to the various factors may be very small.

11. The most suitable leaves for measurements of the lamina are those in the centre of the plant.

12. The venation of the leaves is one of the most constant characters of the plant. On hybridization, the parent forms

have been re-isolated in the F_3 and F_4 generations and also constant forms with intermediate venation. Many of the factors involved have a very small external effect.

13. The shape of the leaf in *N. tabacum* may be defined by the ratio length/breadth, position of the greatest width, amount of indentation of the apex, amount of indentation of the base, nature of the insertion, whether auriculate or not. All these characters can be inherited independently of one another. By the hybridization of two forms, in which the indentation factors of the base differ, "petiolate" forms which at once breed true, are produced by the combined action of the factors. All "petiolate" leaves in this species are probably sessile leaves with deep indentations.

14. The irregularities of the surface of the leaves depend probably on several factors. The undulation of the margin in the particular case investigated proved to be due to a single factor which is inherited independently of the factors concerned in the surface of the leaf.

15. Measurements of the size of the corolla show that this organ resembles the leaves in its mode of inheritance.

From the above results the following general conclusions may be drawn :—The data obtained by a study of the characters of *N. tabacum* show that there is no inherent difference in the mode of inheritance of ordinary qualitative characters (such as the colour of the corolla) and of those characters connected with the size of the organs which are subject to fluctuating variability. All the results obtained can be explained by the Mendelian assumption of segregation of characters, combined with the hypothesis that in connection with each character a large number of factors exist, each of which can be inherited independently. This conclusion is supported by the great range of variation in the F_2 generation, the formation of extreme forms in this generation far outside the limits of the parents, the differ-

ences and diminution in the range of variation in the F_3 cultures raised from different variates of the F_2 generation and by the isolation in the F_3 and succeeding generations of forms like the parents and also of intermediate forms which breed true. This isolation of new forms can easily be explained by a rearrangement of the factors.

Pusa,
April 22nd, 1913.

APPENDIX.

DESCRIPTION OF THE TYPES USED IN HYBRIDIZATION.

Type II. Plants late, tall; height 150 cm.; lower internodes short, upper ones long; most of the large leaves borne near the ground; no large leaves in the upper two-thirds of the plant. *Leaves* petiolate, petiole is slightly alate in the lower leaves, more so in the upper ones; the wings are decurrent down the main stem for about 2.5 cm.; leaves inserted at an angle of 90° and bend downwards from the top of the petiole, asymmetric; shape varies from ovate to lanceolate according to the position on the stem; venation acute-angled, secondary veins arising at an angle of about 60°; apex acute; margin entire or slightly undulate; colour blue-green; texture thick; average length of petiole 6 cm.; average length of lamina 49 cm.; ratio length/breadth 2.5. *Inflorescence leaves* petiolate, petiole not alate, inserted at an angle of 60°—90°, lanceolate; apex acuminate; margin generally entire, sometime undulate. *Inflorescence* raised, side branches borne at regular distances up the stem, parallel to but not as long as the main axis. *Flowers* a deep pink colour which does not fade much; length 45 mm. *Calyx* slightly globular and inflated, about one-third the length of the corolla; teeth moderately long and acute. *Corolla* with an orifice 8 mm. in diameter, a broad tube, and the transition between the tube and the dilated portion abrupt; limb not very deeply divided with folds at the junctions of the lobe; lobes very rounded at the base; apical points short and somewhat reflexed. *Capsule* much longer than the persistent calyx, conical; apex blunt.

The anthers burst as the flower expands, not in the bud, and at this period are above the stigma. In the fully open flower the burst anthers are about 5 mm. above the stigma and project well beyond the orifice of the corolla.

Type III. Plants very late, tall; height 150 cm.; lower internodes very short, upper internodes long; some of the lowest leaves lie on the ground, the others are borne at long intervals up the stem. *Leaves* petiolate with alate petioles, the wings of the petiole expand on reaching the stem and are amplexicaul and decurrent for 5 cm.; leaves inserted at an angle of about 60° and bend downwards; shape ovate to cordate; secondary veins arise at an angle of more than 60°; apex acute; margin undulate; leaf undulate; surface puckered; texture thick; colour dark blue green; average length of petiole 5 cm.; average length of leaf 41 cm.; ratio length/breadth 1.5. *Inflorescence leaves* petiolate with very short alate petioles, inserted at an angle of 90°, ovate; apex acuminate; leaf undulate and surface generally puckered. *Inflorescence* with few flowers and with very spreading sideshoots which arise at regular intervals on the upper half of the main stem. The side branches bear very few flowers. *Flowers* pink, the colour easily fades; length 42 mm. *Calyx* globular and inflated, less than one third the length of the corolla; teeth moderately long and acute. *Corolla* with a broad tube and short dilatation, diameter of orifice 8 mm.; the transition between the tube and the expanded portion abrupt; limb not very deeply divided; lobes much rounded, pointed but with no distinct apical points. *Capsule* much shorter than the persistent calyx, conical; apex blunt.

The anthers burst as the flower expands, not in the bud, and occupy a position above the stigma. In the fully open flower, the burst anthers are about 5 mm. above the stigma and project much beyond the orifice of the corolla.

Type IX. Plants early, dwarf; height 104 cm.; lower internodes very short, causing nearly all the large leaves to lie on

the ground. *Leaves* sessile, inserted at an angle of 90°, slightly amplexicaul, lanceolate, lamina much narrowed towards the base, venation acute-angled, secondary veins arising at an angle of 50°; apex acuminate, median leaves prolonged into very long thin points; margin and lamina with deep undulations, lamina raised between the secondary veins, giving the appearance of folds or ridges; colour dark green; texture very thick; average length 56 cm. *Inflorescence* leaves sessile, inserted at an angle of 90° and droop downwards from the base, linear; apex acuminate; the whole leaf is very sinuate and sometimes even twisted. *Inflorescence* conspicuous and raised above the leaves, with numerous side shoots which are almost as long as the main axis and not very spreading. *Flowers* a very pale pink colour, short (36 mm.). *Calyx* tubular with long and acute teeth, more than half as long as the corolla. *Corolla* with a wide orifice (11 mm.), and a broad tube, the transition between the tube and the dilated portion somewhat gradual; limb divided to about half its depth; lobes rounded at the base; apical points short, straight and only slightly reflexed. *Capsule* cylindrical with a somewhat blunt apex; persistent calyx longer than the capsule.

In the unopened bud all the stamens are below the stigma. The anthers burst just as the flower opens while they are still below the stigma or at the most touch the underside with their apices. In the open flowers the stigma is much above the burst anthers and all project beyond the orifice of the corolla. In some of the buds the stigma is visible between the still closed lobes of the corolla.

Type XVI. Plants somewhat early; height 141 cm.; habit very open, internodes long, only two or three leaves lie on the ground. *Leaves* sessile, inserted at an angle of 90° and droop downwards from near the base, amplexicaul, sometimes slightly auriculate, decurrent, lanceolate, lamina slightly narrowed at the base; secondary veins arise at an angle of 50°; apex acuminate; margin entire; lamina flat except

for occasional slight undulations at the base of some of the leaves; colour very light green; texture medium; average length 46 cm.; ratio length/breadth 4.1. *Inflorescence leaves* similar to the lower leaves but much narrower, in some cases linear, and the undulations at the base are more marked. *Inflorescence* raised with long side branches which are somewhat parallel to and not as long as the main axis. *Flowers* few in number, pale pink; length 50 mm. *Calyx* tubular, somewhat inflated, about one-third the length of the corolla; teeth long and acute. *Corolla* slender, with an orifice 8 mm. in diameter; tube slender, the transition between the tube and the dilated portion slightly abrupt; limb divided to about half its depth; lobes rounded at the base; apices very pointed but no apical point. *Capsule* shorter than the persistent calyx, conical; apex pointed.

The anthers burst in the bud when level with the stigma. In the fully open flowers the empty anthers are just above the stigma and generally slightly project from the orifice of the corolla.

Type XXIII. Plants somewhat early; height 136 cm.; leaves few, lower internodes short, causing some of the leaves to be borne very near the ground, upper internodes long; inflorescence raised in a few long slender branches. *Leaves* sessile, inserted at an angle of 90° and bend downwards from near the base, amplexicaul, very slightly decurrent, elliptical, lamina slightly narrowed towards the base; secondary veins arise at an angle of 75°; apex acuminate; margin and base of leaf undulate; surface puckered; leaf not fully expanded but folded on the midrib; colour yellowish green; texture thick; average length 46 cm.; ratio length/breadth 2.3. *Inflorescence leaves* similar to the lower leaves but narrower. *Inflorescence* raised on a few, long, spreading branches. *Flowers* few, pale pink; length 45 mm. *Calyx* tubular, somewhat inflated, a little less than half the length of the corolla; teeth moderately long and acute. *Corolla* with an orifice 8 mm. in diameter; tube broad,

the transition between the tube and the dilated portion somewhat abrupt ; limb divided to about half its depth ; lobes not rounded at the base ; apical points long and sometimes oblique. *Capsule* shorter than the persistent calyx, cylindrical ; apex blunt.

The anthers burst in the bud or as the flower is expanding and are then just above the stigma. In the fully open flower the empty anthers and the stigma maintain their relative positions and are level with the orifice of the corolla.

Type XXXV. Plants somewhat early, short with exceedingly broad leaves ; height 106 cm. ; internodes very short, several leaves lie on the ground. *Leaves* sessile, inserted at an angle of 60° afterwards becoming horizontal, auriculate, amplexicaul, decurrent for about 1 cm., the decurrent portion of the lamina being very broad, elliptical ; secondary veins arise at an angle of 80° ; apex acute ; margin with slight regular undulations ; surface puckered ; colour blue-green ; texture thin ; average length of leaf 48 cm. ; ratio length/breadth 1.6. *Inflorescence leaves* resemble the lower leaves in every particular but are smaller. *Inflorescence* inconspicuous, scarcely raised and much hidden by the large leaves ; side branches few, short and spreading. *Flowers* large, a very deep pink colour which does not fade ; length 50 mm. *Calyx* globular, inflated, about one-third the length of the corolla ; teeth short and obtuse. *Corolla* with an exceedingly broad tube ; diameter of the orifice about 10 mm. ; transition between the tube and the dilated portion abrupt ; limb entire with slight indentations between the lobes which have no apical points. *Capsule* equal in length to persistent calyx, broad, conical ; apex blunt.

The anthers and stigma are at the same level both in the expanding bud and in the fully open flower. The anthers burst just as the flower opens. Both anthers and stigma remain just below the level of the corolla orifice.

Type XXXVIII. Plants somewhat late and tall ; height 134 cm. ; internodes short, giving the plant a somewhat bushy appearance, several large leaves near the ground. *Leaves*

sessile, inserted at an angle of 60°, the upper portions of the leaves tend to become horizontal, amplexicaul, auriculate, decurrent, elliptical, lamina only narrowed just at the base; secondary veins arise at an angle of 70°; apex acute; margin with regular, very small undulations; surface slightly puckered; colour light green; texture thin; average length 47 cm.; ratio length/breadth 1.8. *Inflorescence leaves* similar to the lower leaves. *Inflorescence* not conspicuous and not much raised. Flowers very pale pink in colour; length 45 mm. *Calyx* globular, inflated, about one-quarter the length of the corolla; teeth moderately long and acute. *Corolla* with a wide orifice (diameter 10 mm.), tube exceedingly broad and the dilated portion very short, the transition between the latter and the tube very abrupt (the shape of the corolla in this type is unique among the Indian tobaccos); limb quite entire. *Capsule* longer than the persistent calyx, conical; apex pointed.

The anthers do not burst in the bud but as the corolla expands, when the anthers are well above the stigma. In the fully open flower the burst anthers are about 5 mm. above the stigma and project from the orifice of the corolla.

Type LI. Plants somewhat late, very tall; height 178 cm.; internodes long, leaves borne at regular intervals up the stem, none on the ground; inflorescence not very conspicuous. Leaves sessile, inserted at an angle of 60°, slightly amplexicaul and auriculate, decurrent for 5 cm. or more, the decurrent portion broad; shape elliptical, lamina somewhat narrowed in the basal third of the leaf; secondary veins arise at an angle of about 80°; apex acute; margin very slightly undulate and recurved; surface slightly puffy or puckered; colour dark blue-green; texture very thin; average length 43 cm.; ratio length/breadth 1.8. *Inflorescence leaves* similar to the lower leaves, but with more acute apices. *Inflorescence* with few flowers; the side branches which are borne at the top of the stem are few in number and almost level with the main axis and parallel to it. *Flowers* very pale pink in colour, fading to

white ; length about 45 mm. *Calyx* globular, inflated, less than one-third the length of the corolla ; teeth short and acute. *Corolla* with a wide orifice 11 mm. in diameter and a very broad tube, the transition between the tube and the dilated portion very abrupt ; limb entire but indented and somewhat folded at the junctions of the lobes ; apical points very short. *Capsule* longer than the persistent calyx, conical ; apex pointed.

In the bud before the corolla expands the anthers are found just above the stigma and burst while in this position before the bud opens. In the fully open flower the burst anthers are about 5 mm. above the stigma and project from the orifice of the corolla.

This type has an exceedingly good texture, the leaves are much thinner than in the ordinary Indian tobaccos. It has the great disadvantage, however, that the leaves are much exposed to the wind and do not protect each other as in the more bushy types. For this reason they are often badly torn before they ripen.

STUDIES IN INDIAN COTTONS

PART I

The Vegetative Characters

BY

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The present note is intended to bring up to date the results of the experiments in the improvement of the cottons in the United Provinces of Agra and Oudh. The work which has been in steady progress since the autumn of 1904, was commenced at Saharanpur and continued since 1906, on the Botanical area of the Government Agricultural Station, Cawnpore. During this period a certain number of publications based on this work have been made and are here noted :—

(1) Jour. Asiatic Soc. of Bengal, IV. 1, p. 13.
(2) Do. do. do. V. 1, p. 23.
(3) Proc. Roy. Soc., B. 83, p. 447.
(4) Journal of Genetics I (ii), 3.
(5) Memoirs of the Dept. of Agri. in India, Botanical Series, IV, No. 3.

(6) *The Problem of the Improvement of Cotton in the United Provinces of Agra and Oudh.* Pamphlet published in conjunction with Dr. Parr, Deputy Director, Western Circle, in connection with the U. P. Exhibition, Allahabad, and reprinted in the Agricultural Journal of India, Vol. VI, Pt. 1.

(7) Memoirs of the Dept. of Agri. in India, Botanical Series, IV, No. 5.

In addition, an article of a more general nature on the breeding of cotton has been written for Prof. Fruwirth's "Die Züchtung der landwirtschaftliche Kulturpflanzen."

Of the above, No. 4 contains the fullest detail of the experiments, but is limited to those problems of which the scientific aspect only had been fully developed; moreover, in it the results are only carried down to the F_3 generation. The economic aspect received little notice and has only been treated in briefest outline in the pamphlet (6) and from a very special point of view in the recent memoir (5).

The work divides itself broadly into two sections, the Scientific and the Economic, the former dealing with all those points concerning the characters, and behaviour of these, which it is necessary to ascertain to indicate the most promising lines on which to develop the economic work and the conditions under which this work must be carried out, the latter, with the actual experiments undertaken to effect the desired improvement.

The first step in any work, such as the present, is to ascertain the extent of the material at hand for the purpose of experiment, or, in other words, using the plant as a unit, to determine the number of forms or types it is possible to isolate and cultivate in a condition of purity. Throughout India there are cultivated a series of cottons including numerous and diverse forms. The grouping of these into a systematic series of which the unit is the type, or that form of plant which can be recognised as distinct and remains thus distinct when cultivated under conditions which ensure purity, is the first object and the one which forms the basis for subsequent experiments.

Having ascertained the types it is next necessary, by a comparative study of the points or characters, by which these differ, to determine the main characteristics. The unit of this series of observations is now the character. But the investigation is not limited to the determination of these alone; by crossing types which differ in certain definite characters and tracing the behaviour of these in the offspring, it is possible, not only to ascertain with some clearness what constitutes a unit character but, also, to obtain information as to the behaviour of these units under definite conditions—information which permits efforts aimed at improvement to be undertaken with some confidence.

The plant may be imagined to consist of an aggregate of unit characters,—the presence or absence of an ultimate common base is not here a matter for concern *c.f.* de Vries (11) certain combinations of which are to be found in nature. Improvement consists in a rearrangement of these units with the production of a plant more suited to the conditions of growth and having a more valuable produce. Regarded in this light the possibility of effecting any improvement is seen to depend very largely on the clearness with which the objective receives definition in the mind. In this way only can the most suitable method of obtaining that combination, and the most suitable types to use as parents, be selected with any degree of certainty.

Although the plant forms the central object of study it is not possible to limit observation to this one aspect. The inter-action between the plant and its surroundings is intimate. It is further necessary, therefore, to determine the nature of the surroundings or environment and also, if possible, the conditions which render one type more suitable than another for growth under a particular set of conditions. In the broadest sense the environment includes not only the physical conditions by which the plant is surrounded but also the organic. In other words, there exists an inter-action, not only between the plant and the soil, climate and such physical conditions of growth but also between the plant and its neighbours —in the case of a field crop usually plants of the same species—insects, harmful or otherwise, and organisms causing disease.

This line of investigation has not in the present case received more than general attention. The physical conditions as existing in the province at the present time have been accepted as standard. It is unlikely that any large change either in methods of cultivation or in the extended use of manures will take place in the near future. The main object seems, therefore, to be rather the production of an improved plant under these conditions than the adaptation of the conditions to meet the needs of the plant. The organic conditions in like manner have not formed the subject of especial investigation except in as far as they affect the methods of experiment. Of major importance here is the relation of the plant to its neighbours and to insects. On this relation depends the extent of the occurrence of cross-fertilization in the field. This subject has been treated somewhat fully in a previous memoir (20) and will not receive more than a passing refereuce here.

Before entering in detail into an account of the experimental work which has been undertaken it will not be amiss to review briefly the conditions under which cotton is grown in the Provinces. These Provinces occupy the large alluvial tract lying between the Himalayas on the north and the uplands of Central India. Throughout the entire area cotton is grown, but the relative area under the crop varies considerably. In map A is given the percentage of the *kharif* area under cotton for each district, the figures being derived from the Season and Crop Report for the year 1909-10, in which the cotton crop was 108 per cent. of the normal. From this map it is seen that the largest proportionate area under cotton occurs in the Muttra district at the south-west corner of the Province. Here over 30 per cent. of the *kharif* area is sown to cotton. From this centre the percentage of the *kharif* area under the crop gradually decreases in passing eastwards until, in the east, the crop is practically absent, the total acreage in the Ghazipur district being 3 only. From the shading of the areas showing a certain range of percentages it further appears that, were the units of determination smaller than a district, a series of lines of equal percentages could be drawn which would be found to be V-shaped with their apices pointing towards the east. In map B are given the isotherms

(average mean temperature) for the months June—August, and in Map C the lines of equal rainfall for June to October. The similarity between the direction of these lines and those indicated for equal percentages of the cotton crop is somewhat striking. It seems to follow that, as far as the United Provinces are concerned, the climatic (rainfall and temperature), rather than any other, conditions are the principal factors in determining the percentage area of cotton grown in the various districts. A problem of somewhat different nature refers to the conditions affecting the area sown to cotton in the different seasons. The statistical aspect of this problem has been dealt with by Moreland (25), by whom also reference is made to the aggregation of the crop into certain areas or cotton tracts.

The Genus Gossypium and the Types used in the investigations.

The distribution of the genus *Gossypium* throughout tropical and semi-tropical climates is nearly universal, the cultivation of the numerous forms extends back to the earliest times, and the origin of these forms, as with so many agricultural plants, is lost in antiquity. Owing, moreover, to the commercial value of the crop and to the amount of attention which has been devoted to it from the time that the fibre began to be used as the raw product of an ever-increasing industry, the original limits of cultivation of each form have been broken down so that at the present time it is possible to find in such a country as India examples of all the larger groups of the genus. In many cases the history of these introductions is wanting and the presence of the plant alone bears testimony to the fact. In spite of this intermingling of types, however, it is still possible to recognise two fairly marked groups of cultivated forms which may be termed the New and Old World groups respectively. Perhaps the most constant character by which these two groups can be distinguished is to be found in the bracts which, in the former, are free and, in the latter, united. It is impossible here to enter into a revision of the genus, though there is little doubt that such a revision is necessary. Such revision can only be made after personal study of all the forms in the field, opportunity for which has not been forthcoming. As so commonly occurs in plants

cultivated over wide areas there arises a considerable degree of adaptation to particular conditions, and no single area will be found in which the numerous forms can be cultivated under conditions which admit of successful study. Even among the Indian indigenous forms certain occur which, owing to the lengthened period of vegetative growth, it is impossible to study in full detail under the climatic conditions prevalent at Cawnpore.

While, therefore, opportunity for such revision is lacking, it is possible to indicate reasons which would seem to throw doubts on the present systems. The two most fully developed are those of Todaro, published in 1877 in his "Rel. sulla Cultura dei Cotoni in Italia", and by Watt in 1907 in his "Wild and Cultivated Cottons of the World." The former classification is based on the observation of living plants grown in Italy. The chief defect is the failure to distinguish clearly between the two types of branches—especially the secondary branches. These may be monopodial or sympodial. The value of this particular character in a systematic scheme may be open to some doubt, but the economic importance of clearly recognising the two types is indisputable. This point will be referred to in some detail later. In the latter, this question of habit is again relegated to a position of insignificance. The author has an extended knowledge of the Indian cottons from personal experience and he has made an exhaustive study of the material collected in the vast majority of the herbaria of the world. We are tempted to think that, in a plant like cotton, the material thus preserved may be very misleading. It is not too much to say that, owing to this difference in habit, two totally distinct types might be represented in a herbarium by material showing no recognisable differences. Thus the secondary branch of a sympodial type may appear identical with the tertiary branch of a monopodial type and unless the exact position from which it has been taken has been noted it will be impossible to determine the type to which it belonged. The author attaches considerable importance to the presence or absence of a fuzz in addition to the floss of the cultivated forms. Thus his section II is characterised as Fuzzy-seeded cottons with united bracteoles: his section III as Fuzzy-seeded cottons with

free bracteoles, and his section IV as naked-seeded cottons with the bracteoles free or nearly so. We have recently been in a position to grow and examine a series of cottons from China and among these occur a series of forms which are undoubtedly related to the members forming the author's section II, but the seeds of which are quite naked (21).

From the limited number of general observations we have been in a position to make, it would appear that among the cultivated forms the condition of the bracts is a character of considerable systematic importance. The two groups so separated agree in the further point of their geographical distribution. The origin of most of the cultivated forms is, it is true, unknown or speculative; moreover the numerous efforts to acclimatise exotic forms in various regions of the globe have led to extensive intermingling of types. Nevertheless the group of plants with united bracteoles appear to be typical of the Old World, while that of plants with free bracteoles is similarly typical of the New World, though the natural limits of this group are not so well defined as those of the latter.

The various types used in the course of these earlier stages of these investigations have been given in a previous publication by one of us (22). As has been there stated, the difficulty of cultivating many, and especially the monopodial, types renders a complete survey of the genus at present impossible.

The list of types there given may be here quoted.

Monopodial Types.

Perennial; secondary branches ascending sharply at an acute angle. Leaf factor is less than 2; plant almost glabrous. Bracteoles small, triangular; margin entire or dentate. Corolla yellow. (Plate I).

This plant is the *G. obtusifolium-Roxburgh Flora Indica* of Gammie (15) and Watt (32). The various forms to which the specific name obtusifolium has been given at different times have been dealt with by Burkill (5) .. .. .. Type 1.

Perennial; with secondary branches spreading. Leaf with a factor less than 2. Stem and leaves densely covered with short

hairs. Bracteoles deeply auriculate or reniform, deeply serrate, spreading in fruit. Corolla yellow, petals small. Stigma heavily glandular. Capsule inflated and nearly spherical with a sharp mucronate apex. (Plate II).

This plant is the *G. herbaceum, Linn*, of Todaro (28) and Gammie and the *G. obtusifolium* var. *Wightiana* of Watt (32). .. .. Type 2.

Perennial "tree cotton;" secondary branches ascending sharply at an acute angle. The entire plant of a deep-red, or purple colour. Leaf with a factor greater than 3; frequently with an extra tooth on one or both sides of the central lobe. Bracteoles small, triangular; margins entire or with the tip dentate. Corolla deep-red. Stigma eglandular. Capsule usually 3 celled, ovate. (Plate III).

This plant is the *Gossypium arboreum* of Linn. Sp. Pl.; Parlatore (26); Todaro (28); and the *G. arboreum* type of Gammie (15) and Watt (32). .. .. Type 3.

Sympodial Types.

Annuals with a few only, or none, of the lowest secondary branches monopodia, the remainder sympodia; the monopodial branches ascending and the sympodial spreading.

A tall plant, in later stages drooping under the weight of fruit. Leaf large, with factor less than 2; lobes commonly 3 or with 2 small accessory basal lobes. Young stem and leaves sparsely hairy. Bracteoles small, entire or with few small apical teeth, closely enveloping bud and fruit. Corolla yellow with deep red "eye." Petals large, semi-transparent. Stigma eglandular or with few glands only. Capsule commonly 3 celled, ovate. (Plate IV).

This plant is the *Gossypium indicum, Lamk.* of Gammie (15) and *G. Nanking* var. *bani* of Watt (32). .. .. Type 4.

An erect plant, in later stages drooping under the weight of fruit. Leaf factor less than 2; lobes 5-7. Young stem and leaves hairy. Bracteoles large, entire or with few small apical teeth loosely enveloping bud and in fruit sometimes reflexed. Corolla yellow with deep red "eye;" petals opaque. Stigma eglandular

or with few glands only. Capsule commonly 3-4 celled, ovate. (Plates V & VI). .. .. Type 5.

An erect plant differing from Type 4 in the greater rigidity of the main stem and the greater angle at which the secondary monopodia arise, in this case about 45, and in the corolla which is white. The petals are small, scarcely projecting beyond the bracteoles. (Plates VII & VIII). .. .. .. Type 6.

Plant erect with secondary monopodial branching, when developed, sharply ascending. Leaf factor less than 2 ; flower white. This type differs from the last in two respects. The secondary monopodial branches, if developed, are sharply ascending. Frequently, however, they are absent, and even when present reduced in number in plants where the growth of the main axis has not received a check, to one, or at most, two with vigorous growth. The plant is consequently strongly asymmetrical. For the same reason the length of the vegetative period is very brief and the first flowers develop while the plant is still quite small. Growth continues throughout the season, the plant maintaining a marvellous fertility. (Plate IX). .. .. .. Type 7.

A tall plant, in later stages drooping under the weight of fruit. Leaf factor greater than 3 ; lobes 5-7 with an extra tooth, on one, or both sides of the central lobe frequently developed. Young stem and leaves hairy. Bracteoles entire or with few apical teeth. Corolla yellow with deep red "eye." Stigma eglandular or with few glands only. Capsule 3-4 celled, ovate. (Plate X). .. .. Type 8.

A plant differing from (8) in the colour of corolla only which is white and scarcely protrudes beyond the bracteoles .. Type 9.

Types (4)-(9) fall into the *G. neglectum* and *G. roseum* of Todaro (28), the *G. neglectum, Tod.* of Gammie (15) and the *G. arboreum* vars. *neglecta* and *rosea* of Watt (32).

A tall plant with the main stem weak and early drooping. Leaf factor greater than 3 ; lobes 5-7. Bracteoles entire or with few apical teeth, large and continuing to grow with the developing boll. Corolla pale yellow with deep "eye." Stigma eglandular. Capsule ovate, very large with numerous seeds. (Plate XI).

The plant is the *G. cernuum* of Todaro and Gammie and the *G. arboreum* var. *assamica* of Watt (32). .. .. Type 10.

A tall plant with leaf factor greater than 3 : leaf lobes 5-7, stem and leaves of a deep red or purple colour ; bracteoles entire or with few apical teeth. Corolla with deep-red "eye," petals white, tinged with pink along margin and the portions exposed in the bud. (Plate XII).

This plant is the *G. sanguineum Hassk.* var. *minor* of Gammie (15) .. .. Type 11.

In addition to the above, the following forms have since been subjected to experiment.

Monopodial Types.

Plant tall with long monopodial branches sharply ascending. Leaf with a factor greater than 3, wrinkled. Leaf and stem covered with short hairs. Bracteoles triangular with margin dentate. Flowers yellow or white.

This group appears to contain a number of type which, however, owing to their monopodial habit it has been impossible to isolate with certainty. The commonest form possesses the habit of Type 3 (*G. arboreum. Linn.*), which it also resembles in the form of the bracts, while the wrinkled leaf and presence of short hairs give a marked resemblance to Type 2 (*G. herbaceum. Linn*). The relatively large value for the leaf factor measurement (*E*) gives the leaf a characteristic appearance which is frequently obtained in the offspring of the cross Type 2 × Type 3. The group is grown usually as a mixed field crop in the east of the United Provinces and in Bengal.

The types appear to differ chiefly in the density of the hairs on leaf and stem and in the length of the internode and of the petiole. The group comprises the *G. intermedium* of Gammie (15).

Sympodial Types.

(1) Plant small with monopodial secondary branches few or none. Leaves 3-5 lobed with factor less than 2. Flower

yellow. Boll large. This group includes a series of types received from China, of which the following have been employed :—

Corolla, yellow eyed : seed with fuzz	..	Type 12.
.. .. naked	..	Type 13.
.. .. without eye : seed naked	..	Type 14.

(2) Plant differing from Type 2 mainly in the character of the secondary branches. The group includes a complex series of forms from Persia which has been dealt with by us elsewhere (21). The simplest form is the true *G. herbaceum* of Todaro.

(3) *Gossypium hirsutum, Linn.*—This plant, which yields the bulk of the American cotton crop, has formed the basis of numerous experiments both in the United Provinces and in other cotton tracts of India and is to be found locally throughout the former. Selected plants from cultures derived from various sources have been used.

(4) *Gossypium Stocksii, Mas. Mast.*- A wild form of *Gossypium* found on the limestone hills around Karachi from whence seed was obtained.

Pollination.

The cotton flower is hermaphrodite (Plate XIII). The stigma becomes receptive and the stamens liberate their pollen shortly after the flower opens. These organs are so distributed that self-pollination follows almost immediately. Associated with this arrangement of organs we find that in almost every case self-fertilization is effective. A detailed discussion has been given on a former occasion (20).

When, however, the question of effecting cross-fertilization is considered, the genus *Gossypium*, at least as far as the cultivated forms are concerned (for of wild species *G. Stocksii, M. Mast.* alone has been studied), appears to fall into two marked groups, the members of each of which are fertile *inter se*, but exhibit complete sterility when attempts are made to effect a cross between the two groups. These two groups have already been referred to above as characteristic of the Old and the New World and as respectively characterised by united and free bracts.

The Experiments (A).—The Colour of the Corolla.

The corolla of the cotton flower consists of five petals arising from the base of the staminal column. The petal is frequently, and in the true Indian cottons invariably, possessed of a deep red, or purple eye situated on the claw. In the extra-Indian cottons this eye may be absent, and in this case the petal is self-coloured. The presence or absence of the " eye " appears to be independent of the general colour of the petal and requires to be treated separately.

Omitting for the moment consideration of the eye, the petal may be yellow, white or red. The latter colour is present in Types 3 & 11 only and is not limited to the petals alone, but is here a local manifestation of the presence of a red sap colour which occurs throughout the plants of these types and will be more conveniently treated in detail in a following section (C).

The two petals, then, may be either white or yellow, and of the latter type two forms are readily distinguished. In the one the colour is a full yellow, described in the subsequent text simply as ' yellow,' while in the other, found only in Type 10, the colour is very light—a condition which will be denoted below as ' pale-yellow.'

The yellow colour is dependent on a colour—producing factor which, according to its presence or absence, gives rise to a simple pair of alellomorphic characters, of which the presence of the colour—producing factor is dominant in both cases. That is, the yellow is dominant both to pale-yellow and to white.

In Table I are given the results obtained from a cross between Type 8 (yellow) and Type 10 (pale-yellow), while in Table II is given the offspring from a cross between Type 4 (yellow) and Type 6 (white). In both cases the numbers are small and insufficient to give reliable numerical values to indicate the proportion existing between the pairs of characters. A clearer indication is given in Table III, which is derived from the crosses between Type 3 and Type 10 and between Type 3 and Types 7 & 9. These crosses are dealt with in fuller detail below, since, owing to the presence of the red colouring matter found in the sap of Type 3, a pair of factors is here involved.

Type 10 has in no case been crossed with a type possessing a white petal nor, in the constant propagation of this type from natural seed, has a single natural cross with a white flowered type been recognised in spite of the fact that it has been each year cultivated in close proximity to Type 9. This is the more remarkable in that, when self-fertilization is not resorted to, there occur a considerable number of plants with the full yellow petal, which are presumably natural crosses with a yellow flowered parent, though no such parent is growing in the same proximity as is the case with the white flowered type. For the present, therefore, it is impossible to say what relation exists between the two conditions which may be indicated by the presence and absence of the pale-yellow factor. This point is now under investigation. It is clear, however, that this condition does not correspond with that denoted by Balls (2) as lemon yellow which he found to represent the impure stage in the cross between full yellow and white flowered parents in the Egyptian cottons.

(*B*).—*The Eye of the Petal.*

As has been noted under the description of types all true Indian cottons possess an eye situated at the base of the petal. In some of the forms received from China, however, the petal is self-coloured yellow. These cottons exhibit complete fertility in the cross with the Indian types and the combined group, therefore, is, in respect to this character, comparable to the Egyptian series of cotton in which the eye may or may not be present. Balls (2) has shown that in the latter group the heterozygote is represented by plant in which the intensity of the eye colour is much reduced. In the examples we have observed such an intermediate condition appears to be rare or non-existent. At the present time crosses in which the eyeless form figures as parent have not been carried sufficiently far—the eyeless type being only recently acquired—to supply definite information of the behaviour of this character. In the F_1 generation of a cross between this form and Type 3 the eye is fully developed, but it is possible that the red sap colour of Type 3 may act as a masking character. Indirect evidence

is given in Table IV. From this table it is seen that, of 15 eyed parents grown under conditions admitting of cross-fertilization taking place naturally, 14 have given eyed forms only and are therefore pure. One only has given eyeless plants in numbers which closely approximate to expectation on the supposition that the parent is impure and presence of the eye is fully dominant over absence. Two only of the eyeless parents have bred pure. Of the 200 offspring of the remaining 4 plants 19 have the eye fully developed, while in the remainder it is absent, a number readily accounted for by the amount of cross-fertilization known to occur, but incompatible with any simple Mendelian ratio. In a single case only has a form appeared in which the intensity of the eye is definitely reduced. This form is being submitted to further investigation.* It would appear, therefore, that the intermediate form of eye found by Balls does not occur in the present group.*

(C). —*The Red colouring-matter in the Sap.*

Type 3 and Type 11 are characterised by the presence of a red anthocyanic colouring-matter in the sap which imparts to the entire plant, stem, foliage and flower, a deep red colour. In these types the intensity of the red in the petal is sufficient to mask the true petal colour entirely, and it is only in a few cases of diseased flowers and of such as open out of season that the presence of the yellow petal colour in Type 3 can be determined by direct observation. When a plant, which breeds pure to this character, is crossed by one in which the red colour is absent, the F_1 generation bears the red colour which may be said to be dominant.

The intensity of the red colour is, however, definitely diminished and the petal attains a condition which has been denoted in the case of a cross with a yellow flowered plant as ' red on yellow.' It is consequently possible to say, from an examination of the petals of plants derived from such a cross, whether the plant is pure with regard to this character or not. From an examination of Table V it

* Since the above was written this form has been found to breed true to the intermediate condition. It must, therefore, represent a further type.

appears, however, that the determination so made is not invariably correct and the method is subject to an error of 22 per cent. A more accurate method has been found for this determination in the young leaves. The red colouring matter in the leaf, from the time this first opens until full development is reached, has been found to have a different distribution which varies with the intensity of the colour. In those plants in which this is developed in greatest intensity the entire leaf, ribs, veins and lamina, are all suffused with a deep red colour. With a diminished intensity the colour becomes restricted to the ribs and veins and, in limiting cases, to the ribs only. These three stages have received the notation of colour to lamina, to veins and to ribs respectively. Plate XIV illustrates 3 examples—the parents of a cross between a pure red form (Type 3) and a form in which the colour is absent (Type 9) with the F_1 in which the colour extends to the ribs. In Table V are collected the records of the determinations of the colour in the young leaf from which it appears that the error is reduced to slightly under 7 per cent.

A series of crosses have been made between Type 3, bearing the red colour, and types in which this is absent and the behaviour of this character may be most readily considered in conjunction with that of the petal colour.

In the cross between Type 3 and Type 4 both parents bear the yellow factor, and in this case a simple pair of allelomorphic characters is under consideration.

In the crosses between Type 3 and the two Types 7 & 9, the yellow factor is present in Type 3 only, while in the cross between Type 3 and Type 10 the yellow factor is again present in Type 3 only, but the case is complicated by the presence of the pale-yellow factor of Type 10.

Such crosses between a red sap coloured plant (Type 3) and one in which this colour is absent have been more than once attempted by other investigators. The earliest on record is that made by Major Trever Clarke in 1867 (Watt 32, p. 336). References to these experiments are scattered throughout the Journal of the Agri. Horticultural Society of India for that period as also in

the Cotton Commissioner's report for 1869 but no detailed report has been traceable. A similar cross is referred to by Fletcher (12), but here again full details are not given. In as much as, however, both red and yellow flowered plants appeared in the F_1 generation, it would appear that the red flowered parent was a heterozygous form. More recently similar crosses have been effected by Main (23). Here, again, the presence of yellow flowered forms in the F_1 seems to indicate that the red flowered parent was not pure but it must be admitted that the numerical results do not agree with any Mendelian expectation. Further the appearance of plants with white flowers in the F_2 generation would indicate that one of the parents was heterozygous with regard to the yellow factor also. That such heterozygous forms are of common occurrence in the field is clear from our own experiments, and the latter case appears to be similar to that observed and detailed by us (20 p. 52).

(1) *Type* 3 × *Type* 4.—This cross has been carried as far as F_5 generation and the results are tabulated in Tables VII, VIII & IX. It is evident that in this instance a single pair only of allelomorphic character is concerned. The two characters comprising this pair are presence and absence of the red colouring-matter—the former condition showing partial dominance over the latter. In Type 3, therefore, the red sap colour masks the yellow colour in the petal, which colour is present in both parents. The F_4 generation is composed of two groups, one derived from protected flowers of the F_3 parent, the second from unprotected parents. The latter group, as Table VIII shows, contains numerous impure plants, the result of natural cross-fertilization. In 1911 when the F_5 generation of this cross was raised, the entire plants were protected under fine mosquito netting. A comparison of Table IX, in which the results of this year are given, with section B of Table VIII indicates that this method of protection, while it does not entirely check cross-fertilization, reduces the amount very considerably. The petal colours of the parents and of the first two generations are illustrated in Plates XV and XVI.

(2) *Type* 3 × *Type* 9.—This cross also has now reached the F_6 generation, and the results are tabulated in Tables X to XIII.

It differs from the above in that Type 4, which has a yellow petal, is replaced by Type 9, in which the petal is white. As far as the present discussion is concerned, therefore, the two parents differ in two characters. Type 3 possesses the two dominant factors representing presence of the red and of the yellow colour, which are both absent in Type 9. Type 3, therefore, represents the condition RRYY and Type 9 the condition rryy. Since it is possible to distinguish the impure form Rr from the pure form RR, it should be possible to recognise in the F_2 generation 6 groups which should possess the following numerical proportions:—

	Flower.	Foliage.	Form.			
(1)	Corolla red	... Colour extending to lamina	RRYY & RRYy	1 2	3	9
(2)	Corolla red	.. Colour extending to veins	Rr YY & Rr Yy	2 4	6	
(3)	Corolla red on white	... Colour extending to lamina	RRyy	1	3	3
(4)	Corolla red on white	... Colour extending to veins	Rryy	2		
(5)	Corolla yellow	... Colourless	rrYY rrYy	1 2	3	3
(6)	Corolla white	... Colourless	rryy	1	1	1

That this expectation is fulfilled is clear from a consideration of Table X, while the close agreement between the expectation and actual results obtained in the subsequent generations, as indicated in Tables XI & XIII, leaves no doubt as to the correctness of this interpretation. Plates XVII and XIX illustrate the different forms of petal arising in this cross.

(3) *Type* 7 × *Type* 3.—This cross, as far as the points at present under consideration are concerned, is in all respects similar to the above. In it Type 7 lacks both factors and therefore possesses the constitution rryy, while Type 3, as has already been shown, has the constitution RRYY. The results of the cross, which has been carried as far as the F_3 generation, are tabulated in Table XIV from which the agreement is apparent.

(4) *Type* 3 × *Type* 10.—The doubt as to the exact constitution of Type 10 as regards the petal colour, has already been referred to above (page 126). In the present case the pale yellow condition

of the petal appears to correspond to the white condition as illustrated in the above two cases (2 & 3). This is illustrated by Table XV. From this it would appear that the pale yellow factor is also present in Type 3 which will be represented by the formula RRYYPP, Type 10 having the constitution rryyPP. That this does not truly represent the constitution of Type 3. appears to be indicated by a cross between Type 3 and Type 9. Assuming Type 9 to have a form rryypp we should expect this cross to produce plants with pale yellow petals. This, however, does not occur. For the present the true constitution of the pale yellow form Type 10 must remain in doubt until the examination of the cross between this type and a white flowered form has been completed.

D.—The Leaf Factor.

This character has been described in detail on a former occasion (22). Opportunity for further investigation has been lacking and the results there recorded need not be reconsidered in this paper.

E.—The Type of branching and the length of Vegetative period.

The inter-dependence between the type of branching and the length of vegetative period is a matter of the utmost practical importance. It is essential that a plant which is to be cultivated on a field scale in the United Provinces should pass through the entire stages and produce an abundance of fruit between the time of sowing in May or, in the case of unirrigated lands, at the beginning of the monsoon and the end of the year. Under these conditions, if a remunerative yield per acre is to be obtained, the plant must commence to ripen its fruit by the middle of October at latest. This means that flowering should commence in the end of August, giving a maximum vegetative period, *i.e.*, the period between the date of sowing and the appearance of the first flowers—of 80 to 90 days—a period which must be considerably reduced in the case of a crop grown on *barani* lands. Table XVI shows that in the monopodial types vegetative period is considerably longer than that of the sympodial types, and too long to render the cultivation of such forms on a field scale practicable. In crosses, therefore, which are pro-

duced with the object of transferring the long staple of the monopodial Type 3 to a plant having the sympodial habit, a knowledge of the exact conditions which determine the length of the vegetative period is essential.

In the axil of the leaf of the cotton plant there occur two buds, one main bud to which the second is accessory. Vegetative growth is effected by the development of a monopodium from either of these two buds. Reproductive growth is effected by the development of a sympodium from the former bud only. According as the secondary branch derived from the main bud in the axil of the leaf of the main stem develops into a sympodium or a monopodium, so will the appearance of the first flowers be accelerated or retarded,—in other words, the length of the vegetative period is controlled by the form of the secondary branches. If these branches are all monopodial, the appearance of the first flower will be delayed until the appearance of tertiary, or even more remote, branches. If, on the other hand, the early secondary branches are sympodial the first flowers will appear at a very early stage and the vegetative period will be reduced to a minimum. The extreme types are well illustrated in Plates III & VI. This inter-relation between the type of branching and the length of the vegetative period was first noted by Thompson (30) in 1841. A similar inter-relation has been indicated by Balls (1) in the case of Egyptian and American Upland forms. The same point has more recently been recorded by Cook (6, 7, 8). In the latter publication it is stated that all the branches that bear flowers and fruit before again branching come from lateral or extra-axillary (accessory) buds.* This statement is in direct contradiction to our own observations, according to which the main bud may give rise to monopodial or sympodial branches, while the accessory bud when it develops, invariably† gives rise to a monopodium.‡

* See also McLachlan Bull. 249, Bureau of Plant Industry, U. S. Dept. of Agriculture.

† In the Indian types. It is generally true of all types, but we have observed forms of G. hirsutum in which the sympodial secondary branch produces lateral sympodia. As the sympodium is itself built up by the growth of the main axillary bud, the terminal bud forming the flower, this lateral branch, which arises apparently in the axil of the leaf, is developed from the accessory bud.

‡ See postscript, page 139.

In the pure types the difference between the two groups in which the secondary branches are monopodial and sympodial respectively is readily distinguished. In the monopodial types even the ultimate secondary branches are monopodial. In the sympodial types, however, although single plants are to be found in which no monopodial secondary branches occur, in general a few of the lowest of these branches are monopodial. Thus in Plate VI a single short monopodial branch is developed, and, similarly, one such branch only occurs in Plate IX. Plate VIII demonstrates the maximum development of monopodial branching found in the sympodial types but, even here, the type is quite distinct from the monopodial type illustrated in Plate III. When, however, the progeny of crosses between types belonging to these two groups is considered, every gradation between the two extreme forms is found. In as much as, however, the change from monopodial to sympodial secondary branching is abrupt, the main stem is divisible into two portions, a lower bearing monopodia and an upper bearing sympodia, and this character can be conveniently expressed as the percentage of the stem bearing monopodial branches. Thus 100 will represent, in this terminology, the full monopodial type and 0 the full sympodial type which, however, includes the forms with a few basal monopodia such as are found in pure types. Plate XVIII illustrates an intermediate type represented by the symbol 70. It is clear that this determination can only be made at the end of the growing period and also that, to obtain such a symbol in any particular case, the main axis of the plant must continue to grow. Unfortunately, in practice, this occurs in comparatively few cases. Through various natural conditions, and especially owing to the attacks of larvæ of *Earias sp.*, which penetrate the leaf axil of the young cotton plant and bore their way down the stem, the main axis is frequently destroyed and growth carried on by lateral branches. In such cases, this determination is not possible, and it is necessary to resort to some other method for determining the character of the plant. Such is to be found in direct measurement of the length of the vegetative period.

The vegetative period has been defined as the period between the date of sowing and the date of appearance of the first flower and may be measured as the number of days. This period is in itself definite and also is determinable early in the season. It is, however, subject to the influence of numerous subsidiary forces which make the actual figure obtained for the plant merely the net result of the action of these forces and not an exact measure of the true character. Thus considerable seasonal variations have been found to occur. These are indicated in Table XVI. A comparison between the figures there given and the climatic conditions for the years concerned indicates that a delay in the arrival of the monsoon leads to a considerable shortening of the vegetative period, but that the period is also influenced by the strength of the monsoon is indicated when the amount and frequency of the rainfall is considered. A strong and early monsoon with liberal rainfall leads to vigorous vegetative growth and a delay in the flowering period: with a delayed monsoon the plants remain small and they flower early.

The difference which is induced in the length of the vegetative period by these causes may amount to as much as a month or even more; and the introduction of a seasonal factor becomes necessary in any comparison between cultures of different seasons.

Minor disturbances in the length of the vegetative period may be produced by such causes as the failure of the earliest flower buds to develop into mature flowers. The bud withers and falls, and the true vegetative period is in such cases less than that actually recorded.

The inter-dependence between the type of branching and the length of vegetative period may be indicated by a correlation coefficient. Tabulating the figures obtained from a series of plants derived from a cross between Type 3 and Type 4, of which the type of branching has been determined, as above described, and of which the length of the vegetative period has also been recorded (Table XVII) the correlation coefficient is found to be ·6628, while, for a similar series, a correlation coefficient as much as ·8589 has been obtained. The inter-relation is, therefore, definite, and the two

characters are merely two outward expressions of the same structural peculiarity of which the vegetative period, being most readily determinable, has been adopted in the present work.

Balls (2) has adopted the same method of record. He further has traced out a certain periodicity in the appearance of the subsequent flowers—a periodicity which has not been investigated by us.

When a cross is effected between two plants, one of which belongs to a sympodial, and the other to a monopodial type, the plants of the F_1 generation possess a vegetative period which is intermediate between those of the two parental types. This intermediate position, however, does not correspond to the mean of the two parental values, but invariably approximates in a greater or less degree to that of the sympodial parent.

In the F_2 generation the plants form a continuous series in which every degree of length of vegetative period is obtained. It is noticeable, however, that while those individuals of the F_2 series which have the shortest vegetative period are in flower as soon as, or even before, the plants of the parental type, in no case does the vegetative period equal in length that of the monopodial parental type. In other words, while the full sympodial type appears comparatively frequently the full monopodial type only rarely or never does so. The divergence from the mean length of the parental vegetative periods noticed in the F_1 generation is here even more marked.

Table XIX illustrates the point for 5 separate crosses in which Type 3 is taken as the monopodial parent with a prolonged vegetative period. Owing to the seasonal variation which has been referred to above, it is not possible to make a direct comparison between the successive generations of such crosses. For this reason the comparison must be effected indirectly by reference to the figures obtained in successive years for the parent types. In the present case we appear to possess an example of partial dominance combined with incomplete resolution of the component factors in subsequent generations, though it may be questioned whether such incomplete resolution is a reality. We are dealing here with a case in which the experimental error of the method of record is inde-

terminate, while, from numerous reasons, it is undoubtedly considerable. It is possible, therefore, that it may be sufficient to act as a masking factor.

The plants of the F_3 generation of such a cross may be said in general terms to possess a vegetative period the mean of which will approximate to that of the F_2 parent, from which they were derived. In other words, an F_2 plant with a short vegetative period, will produce offspring which possesses a short vegetative period and in like manner those possessing a long vegetative period will give rise to F_3 offspring with a prolonged period of vegetative growth. This is shown in Table XVIII. In the majority of families given in that table the average length of the vegetative period of the offspring approximates to that of the parents. In certain cases this figure for the offspring is considerably less than the corresponding figure for the parent. This is easily understood when the various influences which affect the date of appearance of the first flower—*e.g.*, fall of the immature flower buds—are considered. In a few cases only does the figure for the offspring show any considerable excess over that of the parent. This difference is not so readily explained. The difference does not become apparent until the F_3 generation is well advanced, and as, in all probability, the influences which produce this difference are such as affect the F_2 plant in its early stages, it is impossible to ascertain them with any degree of certainty.

Conclusion.

In the above we have attempted to give an account of that part of our work which deals with the vegetative characters of the Indian cottons. Though these do not directly concern that portion of the crop which is commercially valuable, yet we have said sufficient to show that they are of considerable indirect importance. The habit of the plant is, as we have shown, dependent in great measure on the method of branching—and on this habit depend such vital points as the suitability of the plant for field culture, and the yield of *kapas* per acre.

The study of the commercially valuable portion of the crop is far more intricate and while a considerable amount of information

has already been gleaned, further study is necessary before it will be possible to put forward a clear and succinct account of the results obtained in this section of the work. We hope, however, to be in a position to do this at no distant date in a second Part.

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POSTSCRIPT.

Since the pesent paper went to press a further note by the same author (O. F. Cook, Circular No. 109, U. S. Dept. of Agr. Bureau of Plant Industry) has appeared and is mainly devoted to a criticism of our interpretation of the system of branching as here propounded. As this circular has reached me in England, where access to our detailed records is not possible, I am unable to enter in any detail into the points involved. I may, however, take this opportunity to deal briefly with the general questions raised.

In this circular (p. 11) it is stated "some stalks are right-handed and others left-handed with respect to the position of the extra-axillary buds and the branches produced by these buds"—in other words, the extra-axillary, or accessory bud, will for a given branch, lie either to the right or to the left of the main axillary bud. This is in full agreement with our observations (Jour. and Proc. Asiatic Soc. of Bengal, New Series, Vol. V, 1, 1909, p. 23). The author proceeds to state that "the axillary buds may be developed into vegetative branches......The fruiting branches arise from extra-axillary buds......" The conditional tense here used implies that, if buds develop, they will give rise to vegetative branches, but that development need not necessarily take place.

Assuming the correctness of these two statements, let us see what must follow in—to take a particular case—a 'sympodial' plant of the Asiatic type of cotton. In such a plant, as I have shewn elsewhere (Jour. of Genetics I, p. 232), the passage from the lower vegetative, to the upper, fruiting, branches is abrupt and, further, when grown under normal conditions, a single branch only develops, the second bud at each leaf axil remains dormant. As the vegetative branch is developed from the axillary, and the fruiting branch from the extra-axillary bud, and as the extra-axillary bud lies constantly either to the right, or to the left of the main bud, it follows that, when the dormant bud on the lower, vegetative, portion of the stem lies to the right, the dormant bud on the upper, fruiting, portion of the stem must lie to the left, and that, conversely, when the dormant bud on the vegetative portion of the stem lies to the left, that on the upper, fruiting, portion of the stem must lie to the right. Observation, however, shews that, in the type of cotton we are considering, the position of the dormant bud is constant throughout the shoot,—a condition I am inclined to believe obtains in the American series of cottons also, though our observations of these are less extensive. It is impossible, therefore, that the two propositions I have quoted can both hold good.

One further point only can be referred to by me here. On p. 12, a reference is made to the influence of environment on the character of the branches: under conditions which dwarf the plants, few, or no, vegetative branches are produced while, under conditions favouring luxuriant growth, the fruiting branches may be replaced or *transformed* into vegetative branches.

In the sympodial types, as defined by us, the extra-axillary, and even the lower axillary, buds remain dormant if the conditions of cultivation are such as to check growth. Under such circumstances no vegetative branches are produced. When, however, the same types are grown under conditions favouring luxuriant growth both buds develop, giving, in the lower portion of the stem, *two vegetative shoots*—a condition incompatible with the second statement quoted—and, in the upper portion, one

reproductive and one vegetative shoot; further, the vigorous growth of the vegetative branches leads, owing to the exclusion of light and air, to the dwarfing, and even to the complete death, of the weaker reproductive branches. Here the vegetative, replaces the reproductive, branch, but does not arise by any process of transformation, for the dormant bud, frequently represented by a weak or dead shoot, lies on the wrong side of the vigorous vegetative branch. A single case only of transformation has been observed by us. It occurs among the Persian series of "herbaceum" cottons, and is referred to in our paper on these types (Memoirs, Dept. of Agr. in India, Bot. Series IV, No. 5). It is in this series of cottons that the widest range of diversity in form of branching is developed, and, in consequence, the series affords a valuable field for observation of the methods of branching.

That environment is able to produce a change of habit is seen to be true for plants of the 'sympodial' type. When, however, we turn to the true 'monopodial' types, no such change can be induced. *Under adverse conditions, no, or a single, vegetative branch is developed in each leaf axil of the main stem*; while, under conditions of vigorous growth, *two vegetative branches* are produced.

For the reasons already given I am unable to follow the author in detail into the minute structure of the branches. I have shown that the two primary assumptions are not supported by observation and that the change of habit induced by varying conditions of environment are due to the relative development of the two types of branches and not to any transformation of the one into the other. These facts point to the fundamental nature of the difference of the two types of branches. The reproductive branches are admittedly sympodial in structure and it seems more natural to infer that they are truly such than to hypothecate a series of torsions in the earlier stages of development.

H. M. L.

Table I.

Type 10 (pale yellow) × Type 8 (full yellow).

F_1	11 plants all full yellow.	
F_2	99 plants full yellow.	41 plants pale yellow.
Ratio	2·4	1
Expectation	3	1

Table II[1].

Flower Colour. Type 4 (yellow coloured) × Type 6 (white flowered).

F_1	68 plants all yellow flowered.			
F_2	109 plants yellow flowered.			52 plants white flowered.
ratio	2·1			1
F_2 plants used as parents	21			13
	5	10[2]	6	13
F_3 yellow	65	35	34	0
F_3 white	0	0	11	100

[1] No difference has been observed between the direct cross and its reciprocal. The two have, therefore, been grouped together in this and subsequent tables.
[2] Number of offspring too small to be a reliable guide to purity of parent.

Table III.

Parents.	F_1.	F_2.	Ratio.	Expectation.	F_3.	Ratio.	Expectation.
Type 7 × Type 3	15 plants red on yellow.	Pure yellows ... 6	...	...	All yellows .. 271	...	...
		Impure yellows ... 16	...	...	Yellows ... 680	2·9	3
					Whites ... 233	1	1
		Unchecked yellows 608					
		Total yellows ... 630	3·2	3			
		White ... 196	1	1	All white ... 121	...	...
Type 9 × Type 3 and reciprocal.	67 plants red on yellow.	Pure yellows ... 74	...	...	All yellows ... 906	...	...
		Impure yellows ... 169	...	...	Yellows ... 2261	2·8	3
					Whites ... 808	1	1
		Unchecked yellows 135					
		Total yellows ... 378	2·9	3			
		Whites ... 133	1	1	All whites ... 1366	...	...
Type 10 × Type 3 and reciprocal.	50 plants red on yellow	Pure yellows ... 1	...	...	All yellow ... 36	...	...
		Impure yellows .. 15	...	...	Yellows ... 255	3·2	3
					Pale yellows... 78	1	1
		Unchecked yellows 310					
		Total yellows .. 326	3·1	3			
		Pale yellows ... 103	1	1	All pale yellows 35	...	...

Table IV.

Parents.		Offspring.	
Number.	Character.	Eyed.	Eyeless.
14	Eyed	454	...
1	Eyed	29	10
1	Eyed	21 6 Eye lightly shaded	.
2	Eyeless	...	34
4	Eyeless	19	181

Table V.

The intensity of the red colouring matter in the petal as an indication of purity.

Flower of F_2 parent recorded as		Constitution, as determined by F_3 offspring, of the form RR	Rr	Total.
(a) Type 3 × Type 4				
Red	..	28	2	30
Red on yellow	.	35	136	171
Total	...	63	138	201
Ratio	...	1	2·2	...
(b) Type 3 × Type 9				
Red	..	11	3	14
Red on yellow	.	46	136	182
Total	...	57	139	196
Ratio	..	1	2·4	..

Table VI.

The intensity of the red colouring matter in the leaf as an indication of purity.

Leaf of F_2 parent recorded as		Constitution, as determined by F_3 offspring, of the form RR	Rr	Total
(a) Type 3 × Type 4				
Lamina	...	61	5	66
Veins	...	2	20	22
Ribs	..	0	116	116
Total	...	63	141	204
Ratio	...	1	2·2	...
(b) Type 3 × Type 9				
Lamina	..	59	4	63
Veins	...	13	2	15
Ribs	...	9	188	197
Total	...	81	194	275
Ratio	...	1	2·4	...

Table VII.

Sap Colour. Type 3 (red flowered) × Type 4 (yellow flowered).

F_1 38 plants with flowers red on yellow and the red colouring matter extending to veins.

	RR		Rr			RR + Rr	rr
F_2 Foliage	(lamina)		(Ribs or Veins)			(Total Coloured)	(Colourless)
	77		147				
Ratio	1·1		2·1			224	69
Used as parents	61 Lamina		5 Lamina			...	1
	2 Veins		136 Veins				...
						204	68
Reference to Table VIII.	1	2	3		4		5
	RR	*RR*	Rr	RR + Rr	rr		rr
F_3 Foliage	(Lamina)	(Lamina)	(Ribs or Veins)	(Total coloured)	(Colourless)		(Colourless)
	1328	832	1692	2524	773		1245[1]
Ratio	......	1·07	2·18	...	1·00		...

[1] And 4 red plants. A consideration of other characters indicates that 2 of these are without doubt either volunteer plants or have arisen through an accidental mixing of seed.

Table VIII.

F_1 of Type 3 × Type 4

	Parents.			Offspring.		
	Number.	Column of Table VII.	Serial No.	Lamina A.	Veins B.	Colourless C.
(*a*) Selfed Series *F* ...	13	1	1	271	...	...
	8	2	2	194	..	...
	12	3	3	167	373	139
Expectation	..	...	..	*170*	*340*	*170*
	13	4	4	...	...	155
	6	5	5	...	...	120
(*b*) Natural Series F_2 ..	5	1	6	108	(1)	...
	27	2	7	625	(83)	...
	37	3	8	203	393	176
	22	4	9	...	(50)	493
	5	5	10	...	(3)	132

Table IX.

F_3 of Type 3 × Type 4.

Composition.	Parents.		Offspring.		
	No.	Reference to Table VIII.	Lamina.	Veins.	Colourless.
RR ..	11	1 A	267	(2)	..
RR .	3	3 A	182	...	...
Rr	5	3 B	76	158	86
rr .	6	5 C	...	...	595
RR ...	12	7 A	94	...	...
RR .	10	8 A	131	(4)	...
Rr ...	4	8 B	16	27	17
rr ..	9	8 C	...	(1)	143
rr ...	7	9 C	...	...	175

Table X.

Flower Colour Type 3 (red flowered) × Type 9 (white flowered).

F1 Type 3 × Type 9 48
Type 9 × Type 3 19

67 plants with red colouring matter as far as veins and the flower with petals red on yellow.

F2 Foliage ...	RR YY, RR Yy (Lamina).			Rr YY, Rr Yy (Veins).									RR yy (Lamina).	Rr yy (Veins).			rr YY, rr Yy (Green).			rr yy (Green).
Flower ...	(Red)			(Red on yellow.)									(Red on white).	(Red on white).			(Yellow).			(White.)
Ratio Expectation ...	89 2·8 3			193 6·0 6									30 1·0 1	78 2·4 2			96 3·0 3			25 0·8 1
Used as parents ...	17	28		37 12[1]			95						17 5[1]	52			17 6[1]	53		22
F3 Foliage ...	RR YY (Lamina).	RR YY RR yy (Lamina).	RR yy (Lamina).	RR YY (Lamina).	Rr YY (Veins).	rr YY (Green).	RR YY RR Yy (Lamina).	Rr YY Rr Yy (Veins).	RR yy (Lamina).	Rr yy (Veins).	rr YY rr Yy (Green).	rr yy (Green).	RR yy (Lamina).	RR yy (Lamina).	Rr yy (Veins).	rr yy (Green).	rr YY (Green).	rr YY rr Yy (Green).	rr yy (Green.)	rr yy (Green.)
Flower ...	(Red).	(Red).	(Red on white).	(Red).	(Red on yellow).	(Yellow).	(Red).	(Red on yellow).	(Red on white).	(Red on white).	(Yellow).	(White).	(Red on white).	(Red on white).	(Red on white).	(White).	(Yellow)	(Yellow).	(White).	(White).
Reference for Tables XI & XII ...	1 201	2 384	3 148	4 117 15[1]	5 226 41[1]	6 124 22[1]	7 273	8 656	9 96	10 231	11 333	12 90	13 215 12[1]	14 204	15 445	16 189	17 249 25[1]	18 682	19 243	20 313
Ratio in each group	...	2·6	1	1	2	1·3	3	7·3	1·0	2·0	3·7	1	...	1·1	2·3	1	...	2·8	1	.
Expectation in each group	.	3	1	1	2	1	2	6	1	2	3	1	...	1		1		3	1	..

[1] Number of offspring too small for reliable identification of the group.

Table XI.

F_3 Type 3 × Type 9 (Selfed Series 1910).

F_2 Parents.					F_3 Offspring.					
					Red on yellow.		Red on white.		Yellow.	White.
Character.	Serial Number.	Composition.	No. of plants.	Column reference to Table X.	Lamina.	Veins.	Lamina.	Veins.	Green.	Green.
					A	B	C	D	E	F
Red Lamina ...	I	RR YY ..	13	1	86	..	..		...	.
Do. ...	II	RR YY ..	4	4	38		.	...	...	.
Do. ...	III	RR YY	2	2	10					.
Do. ...	IV	RR Yy ..	2	2	6		3		...	.
		Expectation	..	..	6	..	8	..		
Do. ..	V	RR YY .	8	7	198		..		...	.
Do. ...	VI	RR Yy ...	10	7	92	..	32	.	...	...
		Expectation	..	..	96	..	32	..		..
Red Veins ...	VII	Rr YY ..	8	5	18	28	...	.	7	...
		Expectation	..	..	13	26	.	..	13	..
Do. ...	VIII	Rr YY ..	2	8	4	14	.	...	4	...
		Expectation	..	..	..	..	..	..	..	..
Do. ...	IX	Rr Yy ...	16	8	52	98	16	34	44	16
		Expectation	..	..	48	96	16	32	48	16
Do. ...	X	Rr YY* or Rr Yy.	9	8	9	17	..	...	3	...
Red on white Lamina	XI	RR yy ..	30	13		...	111	...	...	..
Do. do. ...	XII	RR yy ..	8	3		...	36	...	...	...
Do. do. ...	XIII	RR yy ..	16	14	...		109	...	(2)	...
Do. do. .	XIV	RR yy ..	9	9	...	...	148		...	...
Red on white Veins ..	XV	Rr yy ...	11	15	...	...	12	15	...	10
		Expectation	.	..			9	18	..	9
Do. do. ...	XVI	Rr yy ...	16	10			26	72	...	36
		Expectation	..	..			33	66	..	33
Yellow • ..	XVII	rr YY ...	14	17			...	...	67	..
Do. ...	XVIII	rr YY ..	11	6	...	.	.	...	88	(1)
Do. ...	XIX	rr YY ...	15	11	...		..	..	158	...
Do. ...	XX	rr Yy ..	10	11	...	...			40	21
		Expectation	..	..				..	45	15
Do. ..	XXI	rr YY ..	8	18	...			...	47	...
Do. .	XXII	rr Yy ..	17	18		...			54	19
		Expectation	..	..	..	...		..	54	18
White ...	XXIII	rr yy ..	3	20	.	...		...	...	10
Do. ...	XXIV	rr yy .	8	16	.				...	19
Do. ..	XXV	rr yy ...	8	19	..	.		...	...	37
Do. ..	XXVI	rr yy ..	10	12	...	..	..	...	...	50

* Number of offspring too small for reliable identification of group.

Table XII.

F_4 Type 3 × Type 9 (Natural Series 1910).

F_3 Parents. Character.	Serial Number.	Composition.	Number of parents.	Column reference to Table X.	F_4 Offspring. Red on yellow. Lamina. A	Red on yellow. Veins. B	Red on white. Lamina. C	Red on white. Veins. D	Yellow. Colourless. E	White. Colourless. F
Red Lamina ..	I	RR YY ...	6	1	135	3	...	..	..	..
Do. .	II	RR YY ..	5	4	92	8	...	...		.
Do. ...	III	RR YY ...	1	2	25	2	...	...	.	.
Do. ...	IV	RR Yy ..	3	2	95	11	18	3		..
Do. ...	V	RR YY ..	6	7	54	10	...	...	.	..
Do. ...	VI	RR Yy ..	5	7	40	2	16	...	..	..
		Expectation		..	**42**	..	**14**	..	..	..
Red Veins ...	VII	Rr YY ..	9	5	74	151	...	..	81	
		Expectation	..	..	**76·5**	**153**		..	**76 5**	..
Do. ..	VIII	Rr YY ...	11	8	64	143	..	...	56	...
		Expectation	..	..	**66**	**132**	..	..	**66**	..
Do. ...	IX	Rr Yy ...	15	8	55	133	12	27	79	24
		Expectation	..	..	**68**	**126**	**21**	**42**	**63**	**21**
Red on white Lamina	XI	RR yy ...	4	13	11	5	149	9	.	...
Do. do. ...	XII	RR yy ...	3	3	...	...	5	...	.	...
Do. do. ...	XIII	RR yy ...	7	14	2	10	36	3	..	...
Do. do. ...	XIV	RR yy ...	3	9	9	2	80	1		..
Red on white Veins ...	XV	Rr yy ...	18	15	13	28	93	214	16	125
		Expectation	..		.	..	**122**	**244**	..	**122**
Do. do. ...	XVI	Rr yy ...	3	10	2	5	28	32	1	15
		Expectation	..	..	..	..	**21**	**42**		**21**
Yellow ...	XVII	rr YY ...	4	17	...	2	..	...	124	
Do. ..	XVIII	rr YY ...	5	6	...	1	..	.	225	(1)
Do. ...	XIX	rr YY ...	8	11	...	(18)	...	...	272	..
Do. ...	XX	rr Yy ...	3	11	...	(13)	...	...	69	18
		Expectation	..	..	..	..	..	..	**66**	**22**
Do. ...	XXI	rr YY ...	4	18	...	2	...	...	90	...
Do. ...	XXII	rr Yy ...	17	18	...	12	...	...	413	132
		Expectation	..	..	..	...	.	..	**432**	**144**
Whites ...	XXIII	rr yy ...	1	20	..	...	...	...		39
Do. ...	XXIV	rr yy ...	8	16	...	1	...	...	21	345
Do. ...	XXV	rr yy ..	6	19	...	...	...	...	6	211
Do. ...	XXVI	rr yy ...	3	12	...	1	...	...	...	29

Table XIII.

F, Type 3 × Type 9.

Parents F_1				Offspring					
Character.	Composition.	Reference to Table XI (and group) and XII.	Number.	Red on yellow. Lamina.	Red on yellow. Veins.	Red on white. Lamina.	Red on white. Veins.	Yellow. Colourless.	White. Colourless.
Red Lamina ...	RR YY ...	12 I A	2	15	...	...	...	...	...
Do. ...	RR YY ...	11 III A	1	6	...	...	...	...	...
Do. ...	RR YY ...	11 VI A	1	2	...	...	...	...	...
Do. ...	RR YY ...	12 VI A	4	26	...	...	...	...	...
Do. ...	RR YY ...	11 IX A	1	32	...	...	...	...	...
Do. ...	RR Yy ...	12 VI A	2	25	...	17	...	...	...
Do. ...	RR YY ...	12 IX A	2	42	...	...	...	...	
Do. ...	RR Yy ...	11 IX A	2	155	...	40	...	...	...
Red Veins ...	Rr YY ...	11 IX B	2	79	148	...	...	80	...
Do. ...	Rr Yy ...	11 IX B	2	45	87	13	31	35	15
Do. ...	Rr Yy ...	12 IX B	3	9	26	8	7	10	1
Red on white Lamina	RR yy ...	11 IX C	2	(2)	(1)	191	...	...	...
Do. do. ...	RR yy ...	11 XIII C	2	...	...	141	...	...	...
Do. do. ...	RR yy ...	11 XIV C	4		...	206	...	...	...
Do. do. ...	RR yy ...	12 XIV C	4	...	...	58	...	...	...
Do. do. ...	RR yy ...	12 XVI C	4	...	...	56	...	...	...
Red on white Veins ...	Rr yy ...	11 IX D	3	...	...	63	152	...	68
Yellows ...	rr YY ...	11 VII E	1	...	...	...	...	7	...
Do. ...	rr YY ...	11 IX E	1	...	...	...	...	38	...
Do. ...	rr YY ...	12 IX E	1	...	...	...	...	6	...
Do. ...	rr YY ...	11 XVIII E	6	...	...	...	...	239	...
Do. ...	rr YY ...	11 XXI E	1	...	...	...	...	12	...
Do.	rr YY ...	12 XVII E	4	...	...	...	...	30	...
Do ...	rr YY ...	12 XX E	2	...	...		...	7	...
Do. ...	rr YY ...	12 XXI E	12	...	...	...	...	52	(3)
Do. ...	rr Yy ...	11 IX E	3	...	...	...	...	432	126
Do. ...	rr Yy ...	12 IX E	2	...	...	...	...	12	3
Do. ...	rr Yy ...	11 XXII E	2	...	...	...		25	9
Do. ...	rr Yy ...	12 XX E	2	...	...	...	...	1	4
Do. ...	rr Yy ...	12 XXII E	1	...	...	...	...	8	2
White ...	rr yy ...	12 IX F	4	...	...	...	...	...	14
Do. ...	rr yy ...	12 XV F	4	...	...	...	...	...	42
Do. ...	rr yy ...	11 XXII F	1	...	...	...	...	...	39

TABLE XIV.

Type 7 × Type 3.

F_1 15 plants, with red colouring matter as far as veins and the flower petals red on yellow.

F_2.	Lamina.			Veins.						Lamina.	Veins.		Green.			Green.
	(Red).			(Red on yellow).						(Red on white).	(Red on white).		(Yellow).			(White).
Ratio in each group ... Expectation	129 3·0 3			253 6·8 6						46 1·1 1	107 2·6 2		148 3·5 3			43 1·0 1
Used as parents ...	3	9		2		5				1	6		1	2		3
F_3 Foliage ...	Lamina.	Lamina.	Lamina.	Lamina & Veins.	Green.	Lamina & Veins.		Green.	Green.	Lamina.	Lamina & Veins.	Green.	Green.	Green.	Green.	Green.
Flower ...	Red.	Red.	Red on white	Red.	Yellow.	Red.	Red on white.	Yellow.	White.	Red on white.	Red on white.	White.	Yellow.	Yellow.	White.	White.
	22	493	175	118	47	62	16	16	7	7	65	23	84	109	35	26
Ratio in each group Expectation		2·8 3	1 1	2·5 3	1 1	9 9	2·3 3	2·3 3	1 1	... ...	2·8 3	1 1	... ...	3·1 3	1 1	. .

Table XV.

Type 3 × Type 10.

F_1 Type 3 × Type 10 46
Type 10 × Type 3 4
—
50

Plants with red colouring matter as far as veins and flower with petals red on yellow.

F₂ Flower.	Red and red on yellow.											Red on pale yellow.				Yellow.			Pale yellow.
Ratio.	247 9·3											86 3·3				79 3			17 0·6
Foliage.	Lamina.			Veins.								Lamina.	Veins.			Green.			Green.
Taken as parents ...	1	0		0		12						0	5			0	3		1
F₃* Foliage	Lamina.	Lamina.	Lamina.	Lamina and veins.	Green.	Lamina.	Veins.	Lamina.	Veins.	Green.	Green.	..	Lamina.	Veins.	Green.	Green.	Green.	Green.	Green.
Flower	Red.	Red.	Red on pale yellow.	Red.	Yellow.	Red.	Red.	Red on pale yellow.	Red on pale yellow.	Yellow.	Pale yellow.	...	Red on pale yellow.	Red on pale yellow.	Pale yellow.	Yellow.	Yellow.	Pale yellow.	Pale yellow.
	36	...	...	...	.	62	86	18	29	55	16	..	56	69	34	..	52	15	35
Ratio in each group .	...	...	...	...	..	3·8	5·3	1·1	1·8	3·4	1	...	1·7	2·0	1	..	3·4	1	..
Expectation .	...	...	...	...		3	6	1	2	3	1	...	1	2	1	..	3	1	..

* Partly from natural seed, a few obvious crosses occurred but are not included in the above table.

Table XVI.

Seasonal variation in date of flowering.

Types.			1907.	1908.	1909.	1910.	1911.
Monopodial	Type 2	...	...	207	Not Sown	Not Sown	
	Type 3	...	146	210	145	Not Sown	Not Sown
Sympodial	Type 4	...	83	110	83	94	97
	Type 5	...	80	110	73	90	69
	Type 6	...	90	114	84	108	74
	Type 7		...	96	63	82	53
	Type 8	...	78	106	72	94	61
	Type 9	..	93	117	92	96	75
	Type 10	.	96	115	94	111	84
	Type 11	..	..	...	74	74	52
	Type 12	...	...	. .	. .	.	56
	Type 13	...	.		...	...	57
	Type 14	...	..	...	...	...	57

1907 and 1908. Sown in pots and transplanted.
1909 to 1911. Sown in field.

Table XVII.

The interrelation between the length of the vegetative period and the type of branching.
Type 3 × Type 4. Field Series.

Number of days.	10	20	30	40	50	60	70	80	90	Branching. 2-day period.	Branching. 5-day period.
Below 65	—	1	-	--	—	—	—	—	—	15	20
66	1	--	—	—	—	—	—	---	—	—	
68	—	1	1	—	—	—	—	—	—	25	18
70	3	2	1	—	—	—	—	—	—	16	
72	4	6	3	—	—	—	—	—	—	19	
74	7	11	2	--	1	—	—	—	—	19	19
75	7	15	1	2	—	—	—	—	—	20	
76	10	17	8	2	—	—	—	—	—	—	
78	27	40	29	7	1	--	—	—	—	21	21
80	46	65	32	12	1	1	1	—	—	21	
82	30	76	58	16	7	6	—	—	—	25	
84	24	59	44	16	9	6	2	—	—	27	26
85	6	25	25	13	2	1	—	—	-	32	
86	3	19	18	15	4	6	5	2	—	—	
88	17	33	35	26	13	11	4	2	1	33	36
90	7	17	19	22	12	11	5	2	1	39	
92	5	20	15	16	13	7	13	1	-	40	
94	5	16	20	15	10	10	6	1	—	38	39
95	3	6	11	8	4	7	4	—	—	41	
96	3	7	16	12	13	8	3	2	1	—	
98	6	12	24	31	18	18	10	5	—	43	44
100	4	14	21	30	23	31	16	4	2	47	
102	8	8	18	28	32	20	20	3	2	47	
104	5	9	10	34	25	25	9	1	3	46	49
105	—	2	5	5	8	10	4	1	2	50	
106	4	2	3	7	9	11	5	1	—	—	
108	—	4	9	12	10	19	12	3	—	52	52
110	—	—	2	12	9	18	9	3	1	56	
112	—	—	1	8	13	10	8	1	1	55	
114	1	1	—	4	5	12	7	2	—	56	55
115	—	—	--	4	1	3	1	—	—	52	
116	—	—	—	—	2	—	1		—	—	
118	—	—	1	1	2	6	5	1	—	60	58
120	—	—	—	2	4	2	3	—	—	55	
122	—	—	1	—	2	—	4	1	—	61	
124	—	—	—	1	1	4	2	1	--	61	61
125	—	—	—	1	—	—	2	—	—	55	
126	—	—	—	—	—	—	—	1	—	—	
128	—	—	1	—	—	1	—	—	—	45	59
130	—	—	—	—	—	—	—	—	—	—	
132	—	—	—	—	1	1	—	—	1	66	66
134	—	—	—	—	1	—	—	1	—	65	
Average period.	83	84	88	94	98	100	101	104	104		

Type 3

	Below 80.	80	82	84	86	88	90	92	94	96	98	100	102	104	106	108	110	112	114	116	118	120	122	1[illegible]
397	...	...	...	...	...	...	...	3	2	1	1	...	1	...	1	1	...	1	1	...	...	...	...	
597	...	...	...	...	...	...	...	...	1	1	...	1	...	1	...	...	...	...	...	...	...	...	...	
360	...	...	...	...	...	...	1	...	...	...	...	...	...	1	...	...	...	1	...	...	1	...	...	
685	...	...	...	...	...	...	...	1	1	1	1	2	3	4	...	...	4	...	3	4	1	1	...	
429	...	...	...	...	...	1	...	1	1	...	...	...	...	1	...	2	1	1	1	1	...	...	...	
661	...	...	...	...	...	1	1	1	2	...	...	...	...	1	3	3	3	4	5	1	1	...	...	
583	...	...	...	...	1	...	1	...	2	5	1	1	1	1	3	1	3	4	4	4	...	2	1	
734	...	...	...	...	...	...	...	...	...	...	...	...	3	2	...	...	1	...	...	1	1	...	...	
488	...	...	...	...	...	...	...	...	...	...	...	1	...	1	...	...	...	...	1	...	...	...	...	
742	...	...	...	...	...	...	...	1	...	...	3	...	...	1	1	...	4	2	2	1	1	2	...	
588	...	...	...	...	...	...	...	1	...	...	...	...	...	...	...	...	1	...	...	1	1	...	...	
654	...	...	...	...	...	...	...	...	...	...	...	1	1	...	1	1	...	2	1	...	...	2	...	
718	...	...	...	...	...	...	...	...	1	...	...	2	2	4	2	...	1	1	2	1	2	3	...	
698	...	...	...	...	...	...	...	...	...	...	2	1	1	1	...	...	...	...	...	1	3	...	...	
620	...	...	...	...	...	...	...	...	...	...	...	...	...	1	1	...	...	...	...	1	...	...	1	
760	...	...	...	...	...	...	...	...	...	...	...	2	3	2	1	1	1	...	1	4	2	2	1	
607	...	...	...	...	...	...	...	1	...	...	...	1	1	...	2	...	...	4	3	3	2	...	2	
614	...	...	...	...	...	1	...	1	...	...	...	...	...	...	...	1	1	1	2	...	1	...	...	
402	...	...	...	...	...	...	...	...	...	1	...	...	...	...	2	...	2	3	1	2	1	...	1	
688	...	...	...	...	...	...	...	...	1	2	...	...	1	...	1	3	4	...	2	5	2	2	1	
658	...	...	...	...	...	...	...	...	1	...	1	...	2	...	2	2	5	3	3	4	2	3	4	
700	...	...	...	...	...	...	...	...	...	...	...	1	...	...	...	...	1	...	...	2	1	...	...	
496	...	...	...	...	...	...	1	...	...	1	...	...	...	...	...	...	...	...	...	...	1	1		1
710	...	...	...	...	...	...	...	...	...	...	...	1	4	1	1	3	...	1	...	...	3	1	...	
681	...	...	...	...	...	...	...	...	...	1	...	1	...	1	2	1	1	5	6	5	1	1	1	
663	...	...	...	...	...	...	...	...	1	...	...	1	...	2	...	1	1	1	2	2	...	2	1	
666	...	...	...	...	...	...	2	...	2	1	...	...	...	...	...	1	3	...	2	1	2	...	1	
511	...	...	...	...	...	...	...	1	...	1	2	...	...	1	2	1	3	1	1	6	4	3	1	
732	...	...	...	...	...	...	...	...	1	...	...	...	...	...	...	1	3	4	1	1	1	...	...	
725	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	1	...	1	1	1	...	...	
715	...	...	...	...	...	...	...	...	1	...	...	2	...	1	...	1	1	...	...	...	1	...	2	
405	...	...	...	...	...	...	...	...	...	...	1	1	...	...	...	...	...	...	...	...	...	...	1	
409	...	...	...	...	...	...	1	...	...	...	...	...	...	...	...	1	...	...	...	1	1	...	2	
421	...	...	...	...	...	...	...	...	...	...	...	...	...	1	1	...	...	...	...	2	1	1	...	
674	...	...	...	...	...	...	...	...	...	...	1	...	...	...	...	...	...	1	...	...	...	...	1	
587	...	...	...	...	...	...	...	...	...	...	...	1	1	1	1	...	...	1	1	1	1	1	...	
667	...	...	...	...	...	...	...	...	...	...	1	1	...	1	1	2	1	1	3	2	...	1	3	
664	...	...	...	...	...	...	1	...	2	...	...	...	1	3	...	...	1	1	...	...	1	...	1	
668	...	...	...	...	...	...	1	...	...	...	...	...	...	1	...	1	1	1	2	1	1	...	2	
733	...	...	...	...	...	...	...	...	1	...	...	...	1	...	1	2	...	2	1	1	...	1	...	
427	...	...	...	...	...	...	...	...	...	...	...	...	1	...	1	...	...	...	3	2	2	1	4	
750	...	...	...	...	...	...	...	...	...	1	4	...	2	1	1	...	...	...	4	6	6	1	...	
423	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	1	...	1	1	...	...	
385	...	...	...	...	...	...	...	...	...	...	...	...	2	...	...	...	2	...	1	1	...	...	...	
606	...	...	...	...	...	...	...	...	...	...	...	...	...	2	2	...	1	2	1	3	2	1	4	
704	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	2	2	...	1	2	2	1	3	
489	...	...	...	...	...	...	...	1	1	...	...	...	1	1	1	1	2	1	2	2	2	2	3	
494	...	...	...	...	...	...	...	1	...	1	...	...	1	...	...	1	...	...	1	2	...	...	1	
712	...	...	...	...	...	...	...	...	...	...	...	...	1	...	2	1	1	3	...	3	2	1	2	
422	...	...	...	...	...	...	...	...	...	...	1	...	...	1	...	3	...	3	2	2	4	...	1	
759	...	...	...	...	...	...	...	...	...	...	...	...	1	...	...	...	...	1	1	...	...	2	...	
686	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	1	...	1	...	1	...	
401	...	...	...	...	...	...	...	1	...	1	...	...	2	...	1	...	3	1	...	2	1	2	1	
680	...	...	...	...	...	...	...	...	1	...	...	...	...	1	...	...	...	1	4	4	1	2	1	
697	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	4	...	2	2	1	1	
699	...	...	...	...	...	...	...	...	1	...	...	1	...	1	...	...	...	1	1	2	2	2	...	
716	...	...	...	...	...	...	...	...	...	...	...	...	...	1	...	...	1	...	...	1	1	...	1	
756	...	...	...	...	...	...	...	...	...	...	...	...	...	1	1	1	1	...	...	2	2	1	1	
481	...	...	...	...	...	...	...	...	...	...	...	...	...	1	...	1	2	...	3	2	2	...	...	
424	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	3	2	4	2	3	4	...	
378		...	...	...	...	...	...	...	...	...	2	1	2	1	1	1	1	2	4	1	1	5	4	

.VIII.

ype 9.

26	128	130	132	134	136	138	140	142	144	146	148	150	152	154	156	158	160	Above 160.	Number of plants.	Parents.	Difference.	Offspring.
																			12	117	-16	101
		1																	5	123	-18	105
																			4	109	-3	106
																			26	119	-12	107
																			11	112	-5	107
																			26	109	-2	107
																			36	117	-9	108
		1																	9	139	-30	109
																			3	125	-16	109
																			18	117	-8	109
																			4	115	-6	109
																			9	158	-48	110
																			21	123	-13	110
		1																	11	118	-7	111
																			4	130	-18	112
																			23	130	-18	112
																			19	126	-14	112
	1			1															11	121	-9	112
																			14	117	-5	112
																			26	117	-4	112
																			34	109	+3	112
																			5	114	-2	112
1																			6	127	-14	113
	1									1									20	125	-12	113
1																			29	117	-4	113
	1				1														16	116	+3	113
	1	1								1									20	107	+6	113
	1																		30	138	-24	114
1		1																	16	132	-18	114
																			4	129	-15	114
1	1	1																	13	123	-9	114
1			1																4	120	-6	114
																			7	118	-4	114
																			6	117	-3	114
1																			4	114	..	114
	1																		11	112	+2	114
1																			21	108	+6	114
	2	1	1							1									18	107	+7	114
	1				1														13	106	+8	114
2																			16	139	-24	115
1																			15	118	-3	115
					1	1				1									34	115	..	115
																			3	114	+1	115
					1														8	110	+5	115
2	2																		22	128	-12	116
																			14	128	-12	116
1	1	1	1	1															26	125	-9	116
1	1	1																	13	123	-7	116
																			20	122	-6	116
	1		1				1												20	122	-6	116
																			7	121	-5	116
																			3	117	-1	116
1		2	1																21	116	..	116
2	1		2																20	114	+2	116
3			1																11	113	+3	116
	1																		17	112	+4	116
				1															6	128	-11	117
		1																	15	127	-10	117
1	1	1			1														14	124	-7	117
																			20	118	-1	117
2	1	2			1														33	116	+1	117

	Below 80.	80	82	84	86	88	90	92	94	96	98	100	102	104	106	108	110	112	114	116	118	120	122
623	...	...	...	...	...	...	...	...	...	...		...	...	1	...	...	1	...	...	1	1	...	1
619	...	...	...	...	...	...	...	...	2	1		...	...	1	...	...	...	...	2	2	2	4	1
757	...		...	...	...	...	...	...	...	...	...	1	1		...	...	...	...	...	1	1	...	...
460	...	...	...	...	...	...	...	...	...	...	...	...	...	...	1	1	3	2	...	3	3	2	1
601	...		...	...	...	...	...	...	...	...		1	...	...	...	...	...	...	...	2	1		2
472		...	...	...	...		...		...	...	...		...	...		...	...	...	1	1	...	...	1
395	...		...	...	...	...	1	...	...	...	...	...		...	1	1	1	...	3	1	...	...	...
589	...	...	...	...	...	...	...	...	...	...			...	...	...	1	...	1	1	1	...	...	...
398	...		...	...	...	...	...	...	...			...			...	...	...	1	3	2	1	1	...
743	...		...	...	...	...	...		...	...	...	...	1	2	1	...	...	...	1	...	4	1	2
690	...		...	...	...	...	...	1	1	...	1	2	...	1	...	...	1	5	2	2	5	1	1
383	...	...	...	...	...	...	...	2	...	...	...	...	...	...	1	...	1	...	1	...	3	1	2
570	...		...	...	...	...	...	...	...	...	...	1	...	...	2	...	...	...	...	...	2	2	1
649	...		...	...	...	...		...	...	...	...	...	...	...	1	2	...	2	3	3	5	4	3
625	...		...	...		...	...	...	...		...	...	...	1	1	...	2	3	1	2	3	5	1
435	...	...	...	...	...	...		1	...		...	...	1	...	1	...	2	1	...	1	1		...
471	...		...	...	...	...	...	...	...	1	1	1	...	...		...	...	1	...	1	2	1	4
480	...	...	...	...	...	...	...	...	...				...	...	...	...	...	1	...	1	...	...	2
461	...		...	...	...	...	...	...	...			...	2	...	1	...	...	...	...	...	...	...	
701	...		...	...	...	...	...	...	1		...	...	...	1	1	...	1	2	...	2	1	2	2
748	...		...	...	...	...	1	...	...	...	...	...	...	1	...	...	...	1	6	2	1	3	7
418	...	...	...	...	...	...	...	...	...	...		...	...	...	...	...	2	...	1	...	1	...	1
425	...	...	...	...	...	...	...	...	...	...	...	...	...	...		...	1	...	...	...	...	1	...
695	...	...	...	...	...	...	...	...	...	...	...	...	2	1	...	...	...	1	...	5	3	1	5
386	...	...	...	...	...	...	...	...		...	...	...	...	...		...	...	...	...	2	...	...	...
641	...	...	...	...	...	...	...	...	...	...	...	...	...	...	1	...	...	...	...	...	...	1	
454	...	...	...	...	...	...	...	...	...	...	...	...	...	2	1	...	...	3	1	2	1	...	2
414	...		...	...	...	...	...	...	...	...	...	...	...	...	...	...	1	2	2	...	1	1	1
404	...		...	...	...	...	...	...	...	1	2			...	1	...	...	...	3	1	2	1	8
546	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	1	1	...	...	...	1	...
513	...			...	...	...	...	1	...	...	1		...	...	...	...	1	1	3	3	4	2	5
493	...		...	...	...	...	...	...	...	...	...	...		...	...	1	1	...	2	1	...	...	...
600	...	...	...	...	...	...	...	...	...		...	...	...	...	...	...	...	...	1	...	1	2	1
452	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	2	1	...	2	...
467	...	...	...	...	...	...	...	...	...	...	...	1	1	1	...	...	1	...	2	2	1	...	1
464	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	2	...	1	1	1	3	2
689	...	...	...	...	...	...	...	1	...	...	...	...	...	...	...	...	...	1	2	1		2	...
751	...	...	...	...	...	...	...	...	...		...	...	...	...	...	1	...	...	...	1	3	1	3
430	...	...	...	...	...	...	...	...	...	...		...	...	...	1	1	1	1	2	1	3	3	1
483	...	...	...	...	...	...	...		...	...	...	...	1	1	...	...	...	1	...	1	3	2	1
596	...	...	...	...	...	...	...	...	...	1	...	...	...	...	...	...	1	...	2	...	1	2	...
728	...		...	...	...	...	...	...	...	...	...	1	...	...	...	...	...	...	...	1	3	3	2
482	...	...	...	...	...	...	...	1	...	...	...	...	...	...	...	1	...	...	...	1	...	1	...
722	...		...	...	...	...	...	...	...	...	...	...	1	1	...	2	...	1	1	...	1	...	2
456	...	...	...	...	...	...	...	...	...	...	...	1	1	1	...	...	...	...	1	...	...	...	1
584	...	...	...	...	...	...	...	...	...		...	...		...	1	...	...	...	...	...	...	...	...
650	...	...	...	...	...	...	...	...	...	...	...	...	...	1	...	...	...		...	...	...	...	...
730	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	1	1	3	1	4	2	2
621	...	...	...	...	...	...	...	...	...	...	...	...	...	...	1	...	...	1	1	...	2	1	1
721	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	3	1	1	4	3
470	...	...	...	...	...	...	...	...	...	...	...	...	...	1	...	1	...	...	...	...	...	1	...
367	...		...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	2	...	1
437		...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	1	1	...	...	1	2	2
617	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	1	...	...	...	1	3	2	1
598	...	...	...	...	...	...	...	...	1	...	...	1	...	...	...	...	...	...	1	2	3	...	2
719	...	...	...	...	...	...	...	...	...	...	1	...	1	...	1	1	...	1	2	1	...	...	1
612	...	...	...	...	...	...	...	...	...	...	...	1	...	...	...	...	...	...	...	1	...	1	2
691	...	...	...	...	...	...	1	...	...	...	...	...	...	...	1	...	...	...	...	...	1	...	...
647	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	1	...	...	...	3	2	2	6
736	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	4	2	3	1	1
497	...	...	...	...	...	...	...	...	...	...	...		...	...	1	...	...	...	...	...	...		...

XVIII—*contd.*

26	128	130	132	134	136	138	140	142	144	146	148	150	152	154	156	158	160	Above 160.	Number of plants.	Parents.	Difference.	Offspring.
...	...	1	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	6	130	−12	118
...	1	...	...	...	...	...	...	...	...	...	2	...	...	...	...	...	...	...	18	129	−11	118
...	...	...	1	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	9	127	− 9	118
...	3	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	22	127	− 9	118
1	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	8	126	− 8	118
...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	3	126	− 8	118
...	2	3	...	1	...	...	...	...	...	...	...	...	...	...	...	...	...	...	14	120	− 2	118
...	1	1	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	6	120	− 2	118
1	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	10	120	− 2	118
...	...	...	1	1	...	...	...	...	...	1	...	...	...	...	...	...	...	...	15	115	+ 3	118
1	1	...	1	...	...	1	...	1	...	2	1	...	...	...	...	...	...	...	33	114	+ 4	118
2	...	2	...	...	...	...	1	...	...	...	...	...	...	...	...	...	...	...	17	110	+ 8	118
2	...	...	1	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	12	158	−39	119
1	2	1	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	30	148	−29	119
2	1	2	...	...	...	...	...	1	...	...	...	...	...	...	...	...	...	...	26	137	−18	119
...	...	3	1	...	...	...	1	...	...	...	...	...	...	...	...	...	...	...	14	130	−11	119
1	2	1	1	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	18	127	− 8	119
...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	4	126	− 7	119
...	...	...	...	1	...	...	1	...	...	...	...	...	...	...	...	...	...	...	7	125	− 6	119
...	...	1	...	3	1	...	...	...	...	...	...	...	...	...	...	...	...	...	20	116	+ 3	119
2	...	...	...	1	...	...	...	...	...	...	1	...	...	...	...	...	...	...	33	116	+ 3	119
1	...	...	1	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	7	114	+ 5	119
...	1	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	3	113	+ 6	119
4	2	1	...	1	...	1	...	...	...	...	...	...	...	...	...	...	...	...	27	112	+ 7	119
...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	3	110	+ 9	119
1	1	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	5	138	−18	120
1	...	1	3	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	23	129	− 9	120
2	2	1	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	13	115	+ 5	120
2	1	1	...	2	...	...	1	...	...	...	...	...	...	...	...	...	...	...	27	113	+ 7	120
...	...	...	...	...	...	1	...	...	...	...	...	...	...	...	...	...	...	...	5	143	−22	121
1	1	2	1	1	1	...	...	1	...	...	...	...	...	...	...	...	...	...	29	134	−13	121
2	...	...	...	...	...	...	...	...	...	...	1	...	...	...	...	...	...	...	9	130	− 9	121
...	...	...	1	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	6	130	− 9	121
...	1	1	1	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	7	129	− 8	121
1	3	2	...	2	...	...	...	...	...	...	...	...	...	...	...	...	...	...	20	127	− 6	121
...	1	1	1	...	...	1	...	...	...	...	...	...	...	...	...	...	...	...	14	126	− 5	121
2	...	3	...	1	...	...	...	...	...	1	...	...	...	...	...	...	...	...	14	117	+ 4	121
1	...	...	...	...	...	...	...	...	1	...	...	...	...	...	...	...	...	...	12	117	+ 4	121
2	1	1	1	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	23	114	+ 7	121
1	3	2	1	...	1	...	...	...	...	...	...	...	...	...	...	...	...	...	19	128	− 6	122
...	...	...	...	...	1	1	...	...	1	...	...	...	...	...	...	...	...	...	10	127	− 5	122
...	3	...	1	...	...	1	...	...	...	...	...	...	...	...	...	...	...	...	17	127	− 5	122
...	1	2	...	...	...	...	...	...	...	1	...	...	...	...	...	...	...	...	10	127	− 6	122
1	1	...	2	...	2	1	...	1	...	...	...	...	...	...	...	...	...	...	19	126	− 4	122
1	3	...	...	...	1	...	...	1	...	...	...	...	...	...	...	...	...	...	14	123	− 1	122
...	1	...	1	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	3	117	+ 5	122
2	1	...	...	1	...	...	...	...	...	...	...	...	...	...	...	...	...	...	7	149	−26	123
4	2	1	2	1	...	1	...	...	...	1	...	...	...	...	...	...	...	...	30	132	− 9	123
2	...	...	...	...	...	...	...	1	1	...	...	...	...	...	...	...	...	...	14	130	− 7	123
1	1	1	2	...	...	1	1	...	...	...	...	...	...	...	...	...	...	...	25	129	− 6	123
...	1	1	...	...	...	...	...	...	1	...	...	...	...	...	...	...	...	...	6	129	− 6	123
...	1	1	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	5	128	− 5	123
...	2	...	1	1	...	...	...	...	...	...	...	...	...	...	...	...	...	...	12	128	− 5	123
3	...	...	...	...	...	...	...	...	1	...	...	...	...	...	...	...	...	...	15	125	− 2	128
3	2	2	2	1	...	...	...	...	1	...	...	...	...	...	...	...	...	...	23	124	− 1	123
2	...	3	1	1	...	1	...	...	1	1	...	...	...	...	1	...	...	...	20	122	+ 1	123
2	...	2	...	...	1	...	...	...	...	...	...	...	...	...	...	...	...	...	12	121	+ 2	123
1	...	1	...	...	...	2	...	...	...	1	...	...	...	...	...	...	...	...	9	115	+ 8	123
2	3	3	1	...	...	1	...	...	...	1	...	...	...	...	...	...	...	...	30	148	−24	124
2	2	1	...	1	...	...	1	1	...	...	...	...	...	...	...	...	...	...	22	137	−13	124
1	...	...	...	...	...	1	...	...	...	...	...	...	...	...	...	...	...	...	3	128	− 4	124

	Below 80.	80	82	84	86	88	90	92	94	96	98	100	102	104	106	108	110	112	114	116	118	120	122
453	...	...	...	...	...	...	...	...	...	...	1	1	1	1	1	...	...	1	...	3	1	...	2
726	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	1	1	1	...	3
753	...	...	...	...	...	...	...	...	...	...	...	...	1	...	...	...	...	...	...	1	...	...	2
669	...	...	...	...	...	...	...	1	...	...	...	...	...	...	...	1	...	...	...	2	2	1	3
379	...	...	...	...	...	...	...	...	...	...	...	1	...	...	...	...	...	...	...	...	2	...	1
366	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	3	...	1
727	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	1	...	...	1	1	...	...	1
720	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	1	1	2	1
426	...	...	...	...	...	...	...	...	...	...	...	1	...	...	...	...	...	1	1	2	2	2	...
386	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	1	1	...	...	2	...
655	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	1
560	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	1	...
624	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	2	...	1	...	...	1
451	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	1	...	2	1	1	1	2
479	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	1	1	1	1	...	...	3
504	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	1	...	...	1
703	...	...	...	...	...	...	...	...	...	1	...	...	...	...	...	...	...	1	...	...	1	3	3
457	...	...	...	...	...	...	...	...	...	...	...	...	...	...	1	1	...	1	3	2	1	1	3
485	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...
498	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	1	...	1	...
752	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	1	...	...	...	...	4	...	1
692	...	...	...	...	...	...	...	...	...	...	...	...	1	...	...	...	1	...	...	...	1	...	...
740	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	1	...	...	1
571	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	1	2
735	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	3	1	2
637	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...
731	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	1	1
627	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	1	1	1	...	1	2	3
486	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	2	1	...	2
490	...	...	...	...	...	...	...	...	...	1	...	...	...	...	...	...	...	1	...	3	2	1	...
717	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	1	...	1	...	1
724	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	2	1	2
505	...	...	...	...	...	...	...	...	...	...	...	1	...	...	...	...	...	...	...	2	1	1	2
487	...	...	...	...	...	...	...	...	1	...	...	...	...	...	...	...	...	...	2	1	1	2	...
476	...	...	...	...	...	...	...	...	...	...	1	...	...	...	1	...	...	...	...	...	1	2	3
491	...	...	...	...	...	...	...	...	...	...	...	...	...	...	1	...	...	1	1	...	...	3	2
492	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	2	...	...	...	...
696	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	1	...	1	1
400	...	...	...	...	...	...	...	...	...	...	...	...	...	1	...	...	...	...	1	2	1	2	2
557	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	1	1	1	1
519	...	...	...	...	...	...	...	...	...	...	...	...	...	1	...	...	...	...	...	2	1	...	2
635	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	1	...	2	4
639	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	1	...	1
478	...	...	...	...	...	...	...	...	...	...	...	1	1	...	...	...	...	...	4	...	...	...	4
601	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	1	...	...	1	...
407	...	...	...	...	...	...	...	...	...	...	1	...	...	...	...	...	...	...	...	...	1	1	1
581	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	1	1	...	1	3	4	...	...
646	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	1	...	1	1	2
729	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	1	...	1	1	2
370	...	...	...	...	...	...	...	...	...	...	...	...	...	1	...	...	...	...	1	...	...	...	1
517	...	...	...	...	...	...	...	1	...	...	...	1	...	...	...	...	...	...	...	...	2	3	2
484	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	2	2	...	1
543	...	...	...	...	...	...	...	...	...	...	...	...	...	...	1	...	...	1	...	1	1	...	...
550	...	...	...	...	...	...	...	...	...	...	...	...	...	1	...	1	...	...	...	...	...	...	1
545	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	1	1	1	...	...
527	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	1	...	...	...	...
636	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	1	5	1	1	...
611	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	1	...	...	...
440	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	1	1	...
608	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	1
613	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	1	...	...	...	...	...	1	...

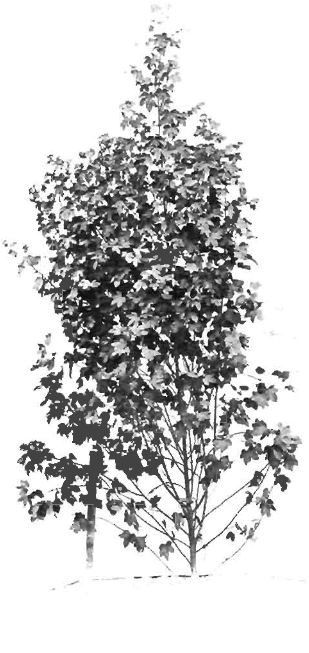
126	128	130	132	134	136	138	140	142	144	146	148	150	152	154	156	158	160	Above 160.	Number of plants.	Parents.	Difference.	Offspring.
2	1	4	3	2	1	1	...	...	...	...	...	...	...	...	...	...	...	1	31	128	-4	124
...	...	...	...	...	...	1	...	...	1	...	...	...	...	...	...	...	...	...	11	126	-2	124
...	...	1	...	...	...	...	1	1	...	...	...	...	...	...	...	...	...	...	7	115	+9	124
1	1	...	...	1	1	1	1	...	...	...	...	1	...	...	...	...	...	...	20	108	+16	124
...	2	1	...	...	...	...	...	...	...	...	1	...	...	...	...	...	...	...	10	98	+26	124
...	1	...	...	...	...	...	...	...	1	...	...	...	...	...	...	...	...	...	11	127	-2	125
...	...	1	...	...	1	...	...	...	...	...	1	...	...	...	...	...	...	...	7	126	-1	125
1	1	1	...	1	...	...	...	...	1	...	...	...	...	...	...	...	...	...	11	126	-1	125
2	1	1	...	...	...	...	...	1	1	...	2	...	...	...	...	...	...	...	20	117	+8	125
2	...	...	...	...	...	...	...	1	1	...	...	...	...	...	...	...	...	...	9	115	+10	125
...	2	...	...	1	...	...	...	...	...	...	...	...	...	...	...	...	...	...	6	155	-29	126
...	2	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	3	155	-29	126
2	...	...	1	...	...	...	...	1	...	...	1	...	...	...	...	...	...	...	10	129	- 3	126
...	2	4	2	...	...	1	...	...	...	...	...	...	1	...	...	...	...	...	20	128	- 2	126
3	3	4	1	1	...	1	...	1	...	...	...	...	...	...	...	...	...	...	24	123	- 2	126
2	1	...	...	...	...	1	...	...	...	...	...	...	...	...	...	...	...	...	6	126	...	126
1	3	2	...	1	...	1	...	1	1	1	1	...	...	...	...	...	...	...	24	126	...	126
1	2	3	2	...	...	1	...	...	...	2	...	1	1	...	...	...	...	...	29	124	+ 2	126
4	...	1	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	6	123	+ 3	126
...	1	...	...	...	...	...	1	...	...	...	...	...	...	...	...	...	...	...	4	121	+ 5	126
...	2	1	3	1	1	...	...	1	...	...	...	...	...	...	...	...	...	...	16	115	+11	126
...	...	1	...	...	...	...	1	...	...	...	1	...	...	...	...	...	...	...	6	115	+11	126
4	...	1	...	1	...	...	...	...	...	...	...	...	...	1	...	...	...	...	13	164	-37	127
1	1	...	2	...	...	...	1	...	...	...	...	...	...	...	...	...	...	...	10	160	-33	127
...	1	...	...	...	...	...	...	...	1	...	...	...	1	...	...	...	...	...	9	138	-11	127
...	1	1	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	3	134	- 7	127
1	...	...	...	...	1	1	...	...	...	...	...	...	...	...	...	...	...	...	6	134	- 7	127
1	3	2	...	1	...	1	1	...	...	...	1	...	...	...	1	...	...	...	26	134	- 7	127
3	2	1	1	...	1	...	2	...	...	...	1	...	...	...	...	...	...	...	19	130	- 3	127
1	...	...	1	1	...	...	...	1	1	...	3	...	...	...	...	...	...	...	16	130	- 3	127
1	2	1	...	1	2	...	...	...	1	...	...	...	...	...	...	...	...	...	13	130	- 3	127
3	2	1	1	3	1	...	...	...	1	...	...	...	...	...	...	...	...	...	20	130	- 3	127
1	4	...	...	1	...	...	...	...	...	1	2	...	...	...	...	...	...	...	19	129	- 2	127
2	2	4	...	...	...	...	1	...	...	2	...	...	...	1	...	...	...	...	21	128	- 1	127
1	3	2	2	1	3	...	1	...	...	...	1	...	...	...	...	...	...	...	25	126	+ 1	127
1	2	1	4	2	...	1	...	...	...	...	1	...	...	...	...	...	...	...	22	123	+ 4	127
...	...	1	1	1	1	...	...	...	...	...	...	...	...	...	...	...	...	...	7	123	+ 4	127
1	...	...	...	1	1	...	...	1	...	...	...	...	...	...	...	...	...	...	7	120	+ 7	127
2	2	...	3	1	...	2	2	1	...	...	...	...	...	...	...	...	...	...	23	111	+16	127
...	1	...	3	...	1	...	...	1	...	...	...	...	...	...	...	...	...	...	11	140	-21	128
1	2	1	...	1	...	2	1	...	2	...	...	...	...	...	...	...	...	...	20	136	- 8	128
2	4	1	1	2	...	1	...	...	2	3	...	...	...	...	...	...	...	...	29	134	- 6	128
2	3	...	2	1	...	...	...	...	...	...	1	...	...	...	...	...	...	...	11	132	- 4	128
3	2	3	...	2	1	2	1	1	2	1	...	...	...	...	...	...	...	...	30	129	-1	128
...	2	1	...	...	1	1	...	...	...	...	...	...	...	...	...	...	...	...	8	128	...	128
1	3	...	1	...	...	2	...	...	...	...	1	1	...	...	...	...	...	...	16	119	+9	128
2	1	3	1	...	2	1	...	...	1	4	...	...	...	...	...	...	...	...	25	113	+15	128
2	3	...	1	...	...	1	1	2	1	...	1	...	...	...	...	...	...	...	19	149	-20	129
...	1	...	...	2	2	2	...	1	...	...	...	...	...	...	...	...	...	...	13	134	—5	129
5	1	...	...	3	...	1	...	1	...	2	...	...	...	...	...	...	...	...	18	133	-4	129
3	5	4	1	...	1	1	4	1	1	1	2	...	...	...	...	...	...	...	35	132	-3	129
2	4	...	3	1	...	1	2	...	1	1	...	...	...	...	...	...	...	...	22	128	+1	129
4	1	1	...	...	...	...	...	1	...	1	1	2	...	...	...	...	...	...	19	142	-12	130
...	...	1	...	...	1	...	...	...	...	...	...	...	1	1	...	...	...	...	7	141	-11	130
1	...	...	2	2	...	...	...	...	1	...	1	...	...	...	...	...	...	...	10	141	-11	130
...	1	2	...	1	...	1	...	1	...	...	...	...	...	...	...	...	...	...	9	137	- 7	130
...	1	5	2	5	1	1	1	1	4	...	...	1	1	...	...	...	...	...	37	132	-2	130
1	1	1	...	...	...	1	1	1	...	...	...	...	...	...	...	...	...	...	9	129	+1	130
1	1	...	...	1	1	...	...	...	...	1	...	...	...	...	...	...	...	...	7	128	+2	130
1	3	...	...	1	1	...	...	...	...	...	...	...	1	...	...	...	...	...	9	126	+4	130
1	...	...	...	1	1	1	1	1	...	...	...	...	...	...	...	...	...	...	9	123	+7	130

	Below 80.	80	82	84	86	88	90	92	94	96	98	100	102	104	106	108	110	112	114	116	118	120	12
723	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	1	...	2
378	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	1	2
377	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	1
657	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	1	1	...	1
565	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	1	...
562	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	1	[illegible]
532	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	1	...	...	1
372	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	1	...	2
640	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	1	...	...	...	...
523	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	1	2	[illegible]
499	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	1	...	2	...	1
408	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...
761	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	1	...	...	1	...
653	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...
626	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	1	...	1
537	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	1
463	...	...	...	...	...	...	...	...	...	...	...	...	...	1	...	...	1	...	...	...	2	1	...
592	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	1	...	...	2	...
552	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	2	...	...	...
558	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...
539	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	1	1	...	...
375	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...
640	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	1	...	...	...	...
548	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...
518	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	1	1	1	1	...
629	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	1	3	...
602	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	1	...	...	...	1	...
575	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...
554	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	1	...
534	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...
538	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	1	...
572	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	1	...	...
542	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	1	...
525	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...
648	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...
533	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...
477	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...
566	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...
738	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	1	...
510	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	2	...	...	...
522	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	1	...	...	...	...	...
387	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...
651	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...
521	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...
528	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...
561	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...
530	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...
547	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...
559	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...
577	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...
573	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...
755	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...
555	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...
656	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...

VIII—*concld.*

26	128	130	132	134	136	138	140	142	144	146	148	150	152	154	156	158	160	Above 160.	Number of plants.	Parents.	Difference.	Offspring.
1	...	4	2	3	1	...	...	1	1	...	...	...	...	...	...	...	...	...	17	130	...	130
...	...	1	...	...	1	1	1	...	...	...	...	...	...	...	...	...	...	...	8	95	+35	130
3		2	1	1	1	...	...	...	1	...	...	...	...	...	...	...	...	...	11	158	-27	131
1	1	...	1	...	...	...	...	1	...	...	...	1	1	...	...	...	...	...	10	158	-27	131
...	1	3	...	1		...	...	...	...	...	...	1	...	...	...	...	...	...	8	154	-23	131
1	...	1	...	...	...	1	...	2	1	...	...	...	...	...	...	...	...	...	10	151	-20	131
2	2	...	...	...	...	...	...	...	1	2	...	...	...	...			...	...	9	134	-3	131
1	2	1	2	2	...	...	1	...	...	1	...	1	...		...	...	...	...	15	134	-3	131
...	1	1	...	...	...	1	1	...	1	...	...		...	...	...	...	...	...	6	132	-1	131
4	1	3	1	1	...	2	1	5	...	...	1	...	...	...	...	...		...	30	130	+1	131
1	...	...	1	1	...	...	...	...	...	1	1	1	...	...	...	...	...	...	10	126	+5	131
...	1	...	...	1	...	...	1	...	...	...	...	...	...	...	...	...	...	...	4	118	+13	131
2	1	.	...	...	...	1	...	3	...			...	...	...		...	...	...	9	154	-22	132
	2	2	3	...	...	...	...	...	...		.	...	1	...	...	...	...	...	8	146	-14	132
5	5	2	2	...	4	...	2	...	1	...	1	...	...	1	...	...	...	...	28	135	-3	132
...	1	...	...	.	...	...	1	1	...	...	...	...	...	...	...	...	.	...	5	133	- 1	132
...	1	1	.	1	2	1	...	1	1	...	...	...	...	1	...		...	2	21	130	+ 2	132
1	2	1	1	.	2	...	...	...	3	...	...	2	...	.	...	...	...	...	18	114	+18	132
1	2	4	1	1	1	...	1	1	1	...	...	...	1	...	1	...	...	...	18	145	-12	133
...	...	1	...	...	...	...	1	.	...	...	1	...	...	...	...	.		...	5	143	-10	133
1	1	1	...	2	...	...	1	...	1	2	...	.	...	...	...	...	...	...	12	138	- 5	133
1	1	1	1	...	1	...	...	...	...	1	...	.	1	...	...	...	...	...	9	135	- 2	133
...	1	1	...	...	...	1	1	...	1	...	...	...	...	...	...	...	...		6	132	+ 1	133
...	...	...	...	1	...	2	...	...	...	...	...	...	...	...	...	...	...		4	145	-11	134
2	3	3	...	...	2	1	3	4	1	.	2	1	1	1	1	...	...	...	35	136	- 2	134
3	2	2	1	1	...	1	...	6	4	...	1	2	...	...	...	...	...	...	29	130	+ 4	134
...	...	1	2	...	1	1	...	1	1	...	2	...	...	...	...	...	...	...	12	124	+10	134
...	1	2	1	1	...	1	1	1	1	...	...	...	...	...	...	...	...	...	10	109	+25	134
2	1	...	...	1	...	2	1	1	1	...	...	...	...	1		...	...		12	148	-13	135
...	1	...	...	...	...	2	...	...	...	...	...	...		...	...	...			3	137	- 2	135
1	1	...	1	...	1	2	1	...	1	...	1	...	...	...	...	...	.	...	10	130	+ 5	135
	2	...	2	1	...	...	...	1	...	1		...	...	1	...	1	...		11	158	-22	136
5	1	3	2	2		1	2	1	1	...	1	2		1	1	...	...	1	25	145	- 9	136
1	2	...	...	...	1	...	...	2	...	2	1	...	...	...	...	...	...	...	11	138	2	136
1	...	1	...	...	2	...	1	...	...	...	2	...	...		...	...		...	7	142	5	137
1	...	...	1	1	...	...	1	1	1	2			...	2	1	...	.	...	15	132	+ 6	138
...	2	7	2	...	1	2	1	3	4	2	2	1	...	...	...	...	1	1	30	125	-14	139
	1	...	1	1	1	...	...	...	...	2	...	...	...	1	...	...	...	...	7	160	-20	140
...	...	...	1	...	...	...	...	...	1	...	...	...	1	...	1	...	...		5	149	- 9	140
...	...	1	...	2	...	...	...	...	1	...	3	1	...	...	1	...	...	1	12	132	+ 8	140
	...	...	2	...	...	1	...	3	...	1	1	2	...	3	...	...	...	1	18	131	+ 9	140
.	1	2	...	...	...	1	...	1	...	1	...	...	...	1	...	...	2	...	12	117	+23	140
2	...	...	1	3	...	2	...	1	2	1	1	...	2	3	...	1	2	.	25	149	- 8	141
	...	...	...	...	...	1	...	...	...	...	...	...		...	...	...	...	1	3	138	+ 3	141
...	1	5	2	3	...	2	2	...	...	2	3	1	2	...	1	...	...	1	25	134	+ 7	141
2	1	1	1	1	2	...	4	1	2	...	2	2	...	...	...	...	...	2	21	152	-10	142
.	...	...	1	2	...	...	2	4	1	4	...	1	...	1	...	1	...	...	18	140	+ 2	142
1	1	...	3	2	2	...	...	...	2	...	1	3	1	1	1	...	...	1	19	146	- 3	143
	...	...	...	...	1	...	1	...	1	1	...	...	...	1	...	...	1	...	7	156	-12	144
	...	...	1	1	...	...	...	1	2	1	2	...	1	1		...	...	...	10	117	+28	145
	...	1	...	...	...	...	1	1	1	...	...	2	1	1	...	...	...	...	8	161	-15	146
	...	...	...	...	...	...	1	4	1	...	...	1	...	...	...	...	2	...	9	129	+17	146
.	...	1	...	...	...	...	...	1	...	...	...	...	...	...	...	...	2	...	4	141	+ 8	149
	.	...	...	...	...	...	...	...	...	1	2	...	...	1	...	1	1	...	6	154	...	154

PLATE I.



G. OBTUSIFOLIUM.—TYPE I.

PLATE II.

G. HERBACEUM.—TYPE 2.

PLATE III.

G. ARBOREUM.—TYPE 3.

PLATE IV.

TYPE 4.

Plate V.

TYPE 5.

PLATE VI.

TYPE 5.

PLATE VII.

TYPE 6*a*.

PLATE VIII.

TYPE 6.

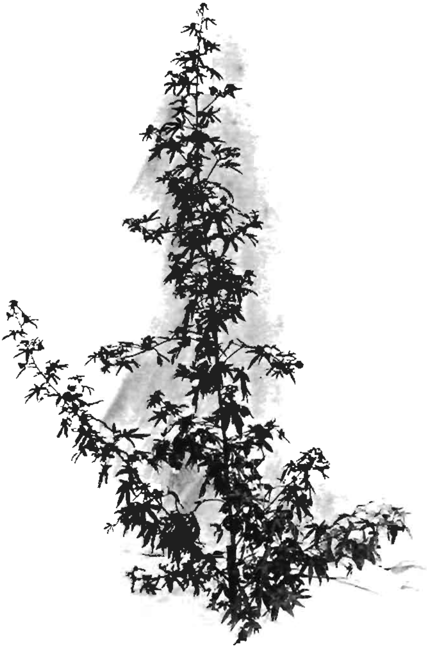
PLATE IX.

TYPE 7.

PLATE X.

TYPE S.

PLATE XI.

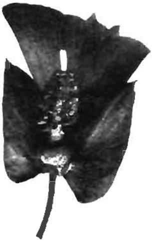


TYPE 10.

PLATE XII.

G. SANGUINEUM.—TYPE II.

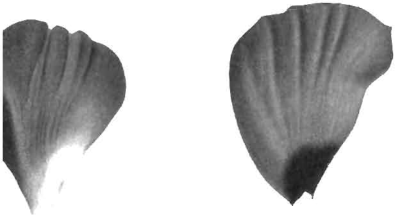
PLATE XIII.



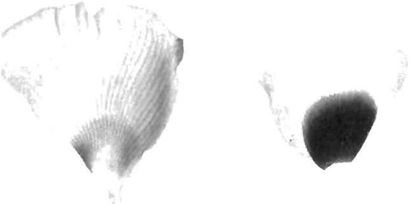
F₁

TYPE 9.

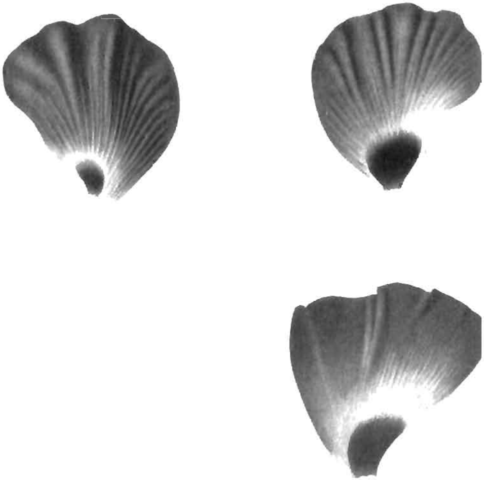
TYPE 3



TYPE 3.



TYPE 1.

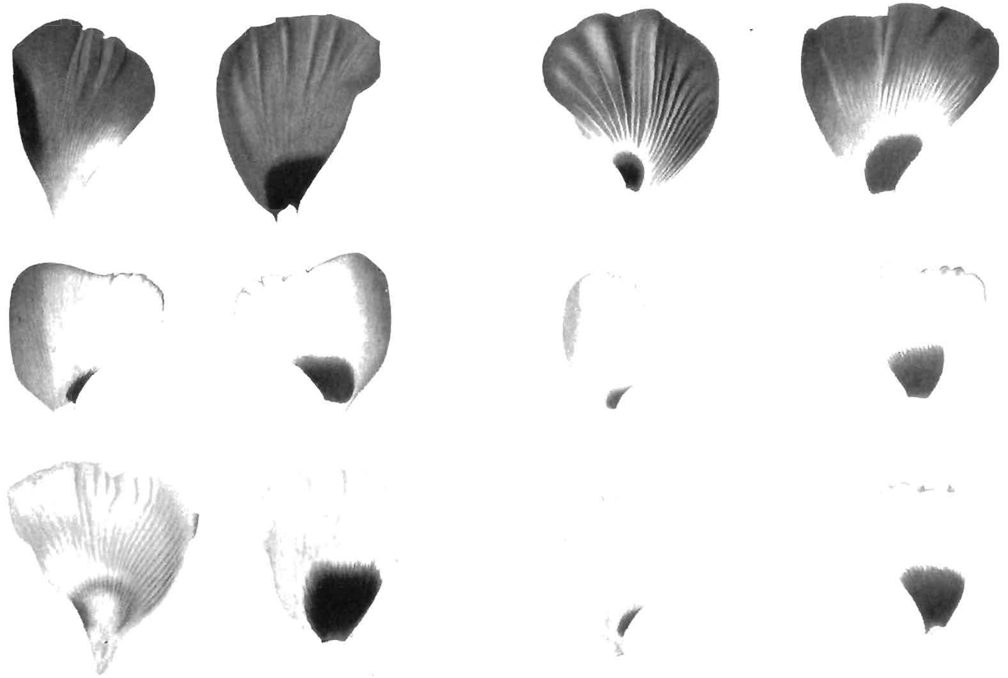


F_1.

Plate XVI

TYPE 3.

F_1



F_2 of TYPE 3 × TYPE 9.

PLATE XIX.

¼ MONOPODIAL TYPE.

RED ROT OF SUGARCANE.

BY

E. J. BUTLER, M.B., F.L.S.,

Imperial Mycologist,

AND

ABDUL HAFIZ KHAN,

Assistant to the Imperial Mycologist.

The most serious disease to which sugarcane is subject in India is undoubtedly that known as "red rot," caused by the fungus *Colletotrichum falcatum* Went. In 1906, a preliminary account of its characters and the damage caused by it in Bengal, especially that part which is now Bihar, was published in these Memoirs.[1] The most important conclusions there come to were that the disease ordinarily results in Northern India from the use of infected canes as "seed" and that the most hopeful method of checking it was by careful selection of the setts at the time of planting.

In a subsequent paper[2] the advantage of this practice was emphasised, some striking illustrations being given. Further experience has only increased the evidence of the value of sett selection which, while not an infallible preventive, is ordinarily instrumental in greatly diminishing the incidence of the disease. It is worth considering this evidence in detail, since infection from diseased seed has recently been denied by American[3] and West Indian[4] writers.

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[1] Butler, E. J. Fungus diseases of sugarcane in Bengal. Mem. Dept. of Agric. in India, Bot. Ser. I, No. 3, 1906.

[2] *Ib.* The selection of sugarcane cuttings. Agric. Journ. of India, II, 1907, p. 193.

[3] Edgerton, C. W. The red rot of sugarcane. Louisiana Agric. Exper. Sta. *Bull.* 133, 1911, p. 11.

[4] Red rot fungus and the sugarcane in the West Indies. Agricultural News, XII, Nos. 286-7-8, 1913.

Sett selection.

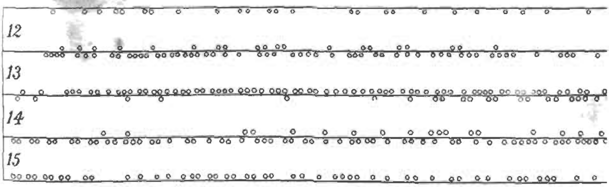
In 1906, alternate rows of diseased and healthy setts of a Madras cane, known as Yerra, were planted at Pusa, on February 26th-27th. Prior to planting, the presence of *Colletotrichum falcatum* had been determined in a large proportion of the canes from which the diseased setts were cut. By the 6th week after planting a decided difference was noticed in the two lots of seedlings. Those from diseased canes were withering in considerable numbers. *Colletotrichum falcatum* was found, in practically every case examined, in the young shoots, usually in the mycelial condition but in several instances producing spores at the basal nodes. In this, as in other cases where it was necessary to determine the identity of the organisms present in diseased cane, considerable use was made of the method of incubating aseptically removed slabs, described on page 8 of the Memoir above referred to. White ants, which are a frequent cause of injury to cane seedlings and which complicate the diagnosis in many cases of fungal attack, were absent from this particular crop, probably because the field in which it was grown was liable to flooding. *Sphæronema adiposum*, a fungus which is able to attack cut setts but not uninjured cane, and a parasite belonging to the genus *Cephalosporium*, which will be described in a subsequent paper, were found in a few cases.

The field in which this crop was grown had not been under cane in recent years and no other cane had been grown the previous year within about half a mile. There was, therefore, no reasonable risk of external infection and certainly no possibility of such an infection as would lead to the death of many plants in the trenches planted with setts from diseased cane, while the alternate, strictly comparable, trenches with healthy seed escaped. The photograph reproduced as Plate XII in the Agricultural Journal of India for 1907, shows the appearance of this plot on May 17th, and could hardly be more decisive. Under the microscope it was easy to trace the fungus from the setts up into the young shoots, and throughout April and May continued infection of the young shoots from their point of

origin occurred. On May 30th the number of sound shoots was counted in the trenches numbered 3 to 18, of which the odd numbers were from healthy seed and the even from diseased, the result being 679 and 117 respectively. The crop was lost by a severe flood in August, so that the final result cannot be given.

In 1907, the experiment was repeated in a field not subject to flooding, ten trenches being sown on March 7th with the varieties Striped Mauritius and Red Mauritius. By the end of April the results were as striking as in the previous year, but in May many shoots withered in the trenches planted with healthy seed of the Red Mauritius variety. This variety was taken from a diseased field and was so generally infected that the ratoons nearly all died out. It is probable that many of the apparently healthy canes contained *Colletotrichum*, for, as will be shown below, while reddening of the pith is a sure indication of disease, unless the canes have been mechanically injured, absence of reddening does not always imply freedom from it.

In 1908, the cane selected was again Red Mauritius, which was planted on March 6th. Germination was good in all the trenches. The condition of four rows, Nos. 12 to 15, on May 30th, is graphically shown below, the small circles each representing a sound shoot. Rows 12 and 14 were from diseased seed, rows 13 and 15 from healthy.



Besides these comparative experiments, the main crop of cane grown on the Pusa Farm has been yearly supervised, so that setts showing red marks in the pith are not planted. The result has been that, excepting the season 1907-08, which will be separately con-

sidered as the cane was weakened by an attack of sugarcane-fly, no serious outbreak of red rot has occurred since 1905-06. The disease is always present and was fairly bad in Yerra in 1905-06 and in Red Mauritius in 1906-07, in both cases accumulating in the following 1st ratoons so as to destroy most of the crop. In 1908-09 it was difficult to find enough diseased cane to supply cultures for experimental work. In other years we have had 5 to 10% diseased. These results are probably better than in any other estate in Bihar, though recently several estates have adopted sett selection. In one such case, that referred to on page 198 of the Agricultural Journal of India for 1907, a very severe attack of red rot occurred in 1905. Sett selection has since been carried out as a routine practice and the Manager reported recently that he has now no disease in his crop.

At the Samalkota Sugar Station in Madras, sett selection has been regularly carried out for the past ten years, at the instance of Dr. C. A. Barber, now Government Sugarcane Expert, Madras. Dr. Barber was, we believe, the first to advocate this method of fighting red rot.[1] In the beginning it was combined with pickling the setts in a strong mixture of lime water and carbolic, with a view to checking moth-borer and the Queensland Acarus "rust", but this was subsequently not considered necessary. In 1906, Dr. Barber stated that it was not possible by the mere rejection of red-marked setts to root out the disease[2]. In spite of all care all but two of the local kinds were found gradually to become worse, until they had to be replaced by new seed from outside. Once these had been discarded, however, better results were obtained. Thus the 1907 report states that selection had a satisfactory effect, disease becoming less every year among the best varieties. In 1908, a severe storm at the end of September was followed by withering of a good many canes. Both Dr. Barber and the senior writer saw the crop in the following February and

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[1] Sugarcane in the Godavari and Ganjam Districts. Dept. of Land Records and Agriculture, Madras, Bull., Vol. II, No. 43, 1901, p. 188.

[2] Barber, C. A. Scientific Report of the Samalkota Agricultural Station for the year ending 31st March, 1906, p. 25.

agreed in considering it remarkably free from red rot, and in holding the injury to the roots caused by the storm responsible for most of the damage. We also found evidence of the existence of a root disease not previously known, which will be described in a subsequent paper. In 1909-10, red rot was still present on the farm but to a far less extent than heretofore. In 1910-11, very little disease was noted either on the farm or in the nursery, though it was still fairly prevalent outside the farm. In 1911-12, red rot was present only to a small extent, though found in nearly all the varieties. From these records it is clear that red rot has not been stamped out by sett selection. It is equally clear that the disease is much less prevalent than in the early years of the existence of the farm. The farm was started as a result of a disastrous outbreak of red rot in the Godavari Delta, which threatened the extinction of cane cultivation in that area. It is fair to assume that the local varieties, which were at first grown, were very largely from diseased stock. So long as these varieties were retained, sett selection did not give satisfactory results. When they were replaced by other, comparatively healthy varieties, sett selection was effective in keeping the disease under control.

It is now necessary to consider why sett selection has proved ineffective in checking disease when the seed was taken from a severely diseased crop.

In selecting healthy setts for planting under field conditions reliance must be placed on the absence of obvious reddening of the pith, visible at the cut ends. Disease was severe in the Pusa crop of 1907-08 and the opportunity was taken of testing how far this method could be relied on. On November 21st, 1907, 6 canes were selected which, on cutting into lengths, were found to have reddened internodes above and below, but in the middle to be free from obvious reddening. In 3 of these, carefnl examination with a lens revealed one or two fine reddened points, corresponding with the cut ends of small bundles; the other 3 appeared quite free from discoloration. Slabs were cut out aseptically and incubated, and the presence of *Colletotrichum falcatum* was demonstrated in one of the six. On

March 17th, 1908, the experiment was repeated with 24 canes slightly reddened at the base but apparently clean higher up. Slabs were cut from above the limit of the discoloration. Of these 15 showed no marks even with a lens, while 9 had minute red points. The presence of *Colletotrichum* was demonstrated in 3 of the former and 1 of the latter. Therefore, in an attack of the severity described, nearly 17 per cent. of apparently clean slabs, taken from canes slightly affected with red rot, were shown to contain the fungus within their tissues. Under such circumstances it would have been necessary to discard all canes, any part of which was discoloured ; new infections were occurring right up to harvest time and some would probably have escaped even such rigorous selection. It would be cheaper and more satisfactory under ordinary estate conditions to discard the whole crop and import healthy seed. In Pusa, since the amount of seed required was small and questions of cost and trouble did not arise, it was found possible to retain some of the more valuable varieties and the 1908-09 crop had little disease. The amount discarded was, however, very great and would have been ruinous under estate conditions.

All that can safely be stated, so far, is that planting setts from obviously diseased canes leads to a considerable development of disease in the resulting crop and that, provided the variety is fairly free from disease to start with, sett selection keeps red rot within reasonable limits, unless some untoward circumstance, such as the epidemic of cane-fly at Pusa in 1907-08, intervenes.

THE INFECTION OF SOUND SETTS.

If there were no other method of perpetuating red rot than by the use of diseased seed, one could, of course, stamp it out, even in view of the above facts. This brings us to the consideration of the parasitism of *Colletotrichum falcatum* and of the means at its disposal for obtaining an entry into previously healthy cane. We can then more readily discuss the further measures for its control and the influence of external conditions, such as the attack of cane-fly at Pusa in 1907-08, on the prevalence of the disease.

As was pointed out formerly,[1] this fungus is not, in Northern India, provided with as suitable a mechanism for spore distribution as in the case with most parasitic fungi. As long as the cane is growing, there is comparatively little risk of air-borne contamination from the stems of diseased plants in the crop. Dead and rotting canes are, however, frequently well provided with spores. Enormous numbers are often found in the pith cavities of old canes. These may contaminate the soil or get into the irrigation water. They may thus reach the newly planted setts. Several experiments have been carried out to ascertain whether infection of sound setts may take place in this manner.

In 1908, a short trench of Purple Mauritius cane was planted on March 7th, the setts in one-half being previously dipped into a suspension of *Colletotrichum* spores, from a pure culture, in distilled water. On April 30th there were 13 living shoots belonging to 12 setts in the non-inoculated half and 6 belonging to 6 setts in the inoculated.

Similar experiments on a larger scale, in 1909, gave conflicting results, both inoculated and control canes showing a number of withered shoots after two months. On May 14th there were 167 healthy shoots and 27 withered in the control trench and 174 healthy and 40 withered in the inoculated. White ants were bad in both, but there was also evidence that *Colletotrichum* had reached the control trench, probably on the feet of the farm labourers, who walked up and down from trench to trench during the irrigation of the crop.

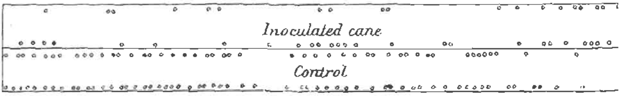
In 1910, the experiment of the previous year was repeated, the cane being sown on March 12th. Germination was slightly better in the control than in the inoculated trench and on May 3rd there were 325 shoots in the former and 304 in the latter. The control trench, which immediately adjoined the inoculated one, developed red rot as in the previous year, probably from infection during irrigation. A similar trench some 30 yards away, but supplied by a separate distributary, was, therefore, also selected for comparison. On June 21st there were only 255 healthy shoots left in the

[1] Butler, E. J., *loc. cit.*, 1906, p. 16.

inoculated trench, while there were 340 in the control trench and 784 in the trench further away.

A form of Colletotrichum falcatum which is truly parasitic on the leaves of sugarcane, was described and figured on page 13 and plate III, fig. 9 of the previous Memoir, and has also been found in Louisiana.[1] The ability of this form to cause typical red rot when introduced through setts has been demonstrated, as the following experiments show. As these experiments have a definite bearing on the question of the propagation of the disease through the setts they are included here, though the leaf form of the fungus will be more fully considered below.

On December 5th, 1907, 21 canes of Red Mauritius were inoculated from a pure culture of the leaf parasite shaken up in distilled water. The inoculations were done by removing a cylinder of cane at a lower internode with a small sterile cork borer, inserting some of the culture in the wound and replacing the cylinder after cutting a piece off the end with a flamed knife, so as to leave a cavity. The stem was then bound with fine sterile gutta-percha sheeting. On March 6th, 1908, the inoculated canes were cut and examined. One had been damaged by a jackal and was discarded. The others were outwardly sound. With 18 of these a trench was planted on March 7th, the canes being cut into the usual setts each with three "eyes." In cutting it was observed that obvious reddening of the pith occurred in from 1 to 3 internodes above the seat of inoculation. The remaining two canes were examined microscopically and the presence of *Colletotrichum* demonstrated. A similar trench was planted alongside, with sound setts from the same plot, to serve as a control. The condition on May 30th is shown graphically below. Red rot was severe in the inoculated trench and practically absent in the other.



[1] Edgerton, C. W., *loc. cit.*, p. 4, Pl. I.

On March 7th, 1908, a short trench of Purple Mauritius was planted, half with setts dipped in a pure suspension of the leaf form of *Colletotrichum*, the other half not inoculated. On April 30th, 62 healthy shoots belonging to 50 setts were found in the latter and 30 belonging to 26 setts in the former. Germination had been approximately equal in the two halves.

On March 12th, 1910, half a trench was similarly planted with setts of Ashy Mauritius, dipped in a pure suspension of the leaf form of *Colletotrichum*. Germination was better in the inoculated than in the control half, and on May 3rd there were 182 shoots in the former and 130 in the latter. On June 21st there were 77 healthy and 80 withering shoots in the inoculated half-trench, while the control half-trench had 156 healthy and 55 withering. As already stated the controls this year developed red rot, probably from infection during irrigation. A full trench of the same cane near by but supplied by a separate distributary had, as above mentioned, on this date 784 healthy shoots.

In all these cases the presence of *Colletotrichum* was demonstrated in several of the withering shoots, and they establish fully that true red rot can arise from infection from both the stem and the leaf forms of the fungus through the planted setts. Not only is the disease perpetuated by planting previously diseased setts, but healthy setts can be infected at the time of planting, if reached by the fungus, and, no doubt, subsequent infection from below ground can also occur. It is well known from previous work that the fungus can enter at wounds exposing the pith, such as the cut ends of the setts, and, as will be shown below, infection through the roots also readily occurs. The course of the infection up into the stem can be traced in many cases and direct connection between the mycelium in the sett and that in the new shoot established. Raciborski[1] has very correctly described the passage of the disease from the planted sett up into the young shoot.

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[1] Raciborski, M. De Bestrijding van het rood-snot. Archief v.d., Java-Suikerindustrie, V, 1897, p. 1133.

THE INFECTION OF GROWING CANES.

It is generally stated by workers outside India that red rot frequently arises from wound infection of the stem of the cane, after it has developed far enough to be exposed to the attacks of stem borer, that is usually in the second half of its growth period. Some observers even hold that this is the only way in which the disease can arise. The results of numerous inoculations, indeed, fully prove that cane can be artificially infected through wounds similar to those caused by insects. But, as was definitely stated by Prinsen Geerligs[1] in 1898, wound infection will not sufficiently explain every case of attack and we hope to show that in Northern India it is of secondary importance.

Went, who first described the disease, obtained successful inoculations by puncturing the rind with a fine needle and inserting conidia of *Colletotrichum*.[2] The infection was, however, localised and after 20 days was chiefly confined to the inoculated internode, traces only being found in the two higher up. Attempts to inoculate the unwounded rind failed, except when very young internodes were selected. Went concludes that natural infection occurs chiefly through the holes made by boring insects, but that the place of insertion of the leaf sheath at the node is also permeable. Howard,[3] ten years later, described the results of inoculations with the same fungus in the West Indies. When wound inoculations were made on vigorously growing canes about 6 months old, the fungus was found to have infected one or two internodes only, after two months. In fully grown cane, during the ripening period, however, infection was much more complete, up to 18 inches of the pith being invaded in less than a month, in one series. Inoculations at the leaf bases were successful in some cases but failed in others. Lewton-Brain[4] did a limited number of inoculations in Hawaii in

[1] Archief, *VI*, 1898, p. 450.

[2] Went, F. A. F. C. Het rood-snot. Mededeelingen Proefstation "West-Java," Archief v. d. Java-Suikerindustrie, I, 1893, p. 265.

[3] Howard, A. On some diseases of the sugarcane in the West Indies. Ann. of Bot. XVII, 1903, p. 373.

[4] Lewton-Brain, L. Red Rot of the Sugarcane stem. Exper. Sta. of the Hawaiian Sugar Planters' Assoc., Div. of Pathology and Physiology, Bull. 8, 1908.

1906-07. Wound inoculations on the stem of Yellow Caledonia (White Tanna) canes were made. After two months the inoculated internode was found to be infected and there appeared to be indications that the disease was spreading through the nodes to the internodes above and below. Ten months later, no further progress had been made. Presumably the inoculations were made on young plants. Infection through borer holes is considered by this writer to be practically the only way in which fresh attacks arise, but the propagation of the disease by planting diseased setts is accepted. Edgerton[1] reports a very large series of inoculations in Louisiana. He states that the disease spreads from the point of inoculation up and down through the cane for from two to five joints during the season, but is not visible externally. Sometimes, however, if the stalk is inoculated very young, the growth of the fungus is so rapid that the whole stalk is killed, but this is not usually the case. Infection through borer burrows is stated to be by far the commonest cause of the disease. Infection through the leaf bases and the rootlet buds at the nodes is considered possible but was not proven. Infection through the planted setts is denied. Selection of setts is advocated, not because they can carry red rot but because the resulting crop should be superior if only healthy seed is used.

Quite recently the results of inoculation experiments by South and Dunlop in St. Kitts and Barbados, are described in the " Agricultural News " (Vol. XII, Nos. 286-7-8, 1913). In the St. Kitts experiments wound inoculations at the nodes and internodes caused limited infection, which ceased to develop after about the first month. In the more susceptible canes the fungus spread quickly throughout the entire internode, but did not penetrate the joints. The cane was strongly growing White Transparent, seven months old. Inoculations on the leaf scars and between the leaf sheaths and the stem failed. Attempts to infect cuttings gave more complicated results. All the inoculated cuttings were reddened throughout after 83 days, while only about half the controls showed reddening

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[1] Edgerton, C. W., *loc. cit.*, p. 5.

in every node and this was less intense as a rule. The latter cuttings had generally a white strand along the side from which the shoots arose. Of 30 inoculated cuttings 8 growing points were found to become diseased : a similar condition was observed in two controls. In one inoculated shoot *Colletotrichum* was identified. The control shoots were more numerous, weighed more and were generally more healthy in appearance than those from inoculated cuttings. In Barbados, 40 setts each of White Transparent, Bourbon, B 147 and B 376 were inoculated before planting, a parallel set being grown as controls. The inoculations took, but growth within the setts was slight, the discoloration being only visible for about 2 by ½ inch round the wound after 6 weeks. There was no definite sign of penetration into the buds at this period. After three months there were 7 withered shoots in the controls and 15 in the inoculated cane. *Colletotrichum* could not be found in the diseased growing tips. The healthy shoots were cut off from the inoculated setts by the formation of a woody partition. The authors conclude that the fungus is a facultative wound parasite, infecting chiefly through wounds such as borer holes, and not carried into the young shoots from infected setts.

Since it is fully established that stem wounds allow of artificial infection, experiments were carried out with a view to ascertain how far this is a common origin of the disease in nature. Practically the only wounds which open a passage direct to the pith are those due to the various stem borers so commonly found in cane. These wounds were tested for *Colletotrichum* on several occasions.

In November, 1907, when red rot was prevalent at Pusa, six canes with borer holes were examined by cutting out aseptically a slab to include the reddened area always found in the immediate vicinity of the hole. On incubation none gave *Colletotrichum*. In the same month the following year the experiment was repeated with 9 bored canes. The result was again negative. In January, 1909, 12 bored canes were similarly examined at Samalkota, with the same result. In addition we have examined by sectioning the neighbourhood of the holes in bored canes on many occasions when the

crop was suffering more or less severely from red rot and have not been able to satisfy ourselves in any case that the disease had originated at the borer hole and not elsewhere. Yet we are satisfied that there are other methods of infection than from below ground and these may now be considered.

Went and Howard both refer to infection through the scar left when the leaf sheaths break away from the stem. In December, 1907, 20 Red Mauritius canes, almost fully grown, were inoculated at the scar left by pulling off a leaf about the centre of the stem. The leaves were old and came away readily. The inoculated portion was kept moist for about 24 hours by covering with moist sterile cotton wool. After three months the canes were examined. One was damaged by a jackal and was discarded. In 3, acervuli with spores of *Colletotrichum falcatum* were found on the surface of the scar. In 11, there was no reddening of the tissues and no sign of penetration. In 5, there was slight reddening at or near the node. No hyphæ, however, could be found and on incubating slabs, cut so as to include the reddened parts, no *Colletotrichum* developed. Even in the 3 cases where the fungus had fructified on the spot, no penetration occurred.

At the cane node there are two other points of discontinuity in the rind, where the shoot bud (the "eye") comes through and where the eyes of the adventitious roots occur. These were found to admit the fungus readily. In April, 1912, 12 buds of Samsara cane were injured by rubbing with the fingers and inoculated with spores and mycelium kept moist by cotton wool as before. One was examined after three days and the hyphæ were found to have penetrated the bud and to be growing vigorously. After eleven days another was examined. The mycelium was still confined to the bud, which was much reddened. A week later the rest were examined. All had taken the infection well and in several the hyphæ had already entered the main stem. Injury to the eye buds, especially as the cane approaches maturity, is unfortunately only too common, and the fungus can readily penetrate if such buds become contaminated. The uninjured

bud is less readily infected. Inoculations made by placing on the bud scales, in a moist atmosphere, fresh acervuli with spores, from a pure culture, showed little progress at the end of a month. There was a slight reddening of the scale, especially along the margin and hyphæ were numerous in the reddened part. The underlying bud layers were only faintly discoloured and very few hyphæ had entered them. The deeper layers of the bud were quite free. The buds were swelling at the time of inoculation and the progress of the infection was so extremely slow that it is doubtful if the young shoot could be reached before the outer layers had withered or lost contact with it. This is in harmony with our general experience that uninjured young shoots are not found attacked by red rot, unless the parent stem is also infected.

The adventitious root eyes are much more easily infected. Twelve Samsara canes were inoculated, in the same manner as in the last experiment, on April 16th, 1912, the root origins being prominent but quite sound and uninjured. On the 24th, 9 were examined and were all found infected, the hyphæ being well established and growing in towards the pith of the main stem. The experiment was repeated on May 22nd, 1913. Four perfectly healthy canes of a thin variety which had a good development of young, clean, adventitious roots, varying from about one-eighth of an inch to one inch in length, were inoculated in the laboratory in the manner described above. The culture used was five days old and 16 roots in all were inoculated. One root was sectioned after a week and found to have taken infection well. The penetration of the hyphæ into the tissues was clearly visible and is shown in fig. 3. Reddening had extended down the root and penetrated about $1\frac{1}{2}$ mm. into the main stem. Characteristic hyphæ of *Colletotrichum* were found in the reddened part of the stem. Two days later 3 more roots were examined, and the same conditions found. On this day the rind at the base of the root was found slightly discoloured and the discoloration extended during the following days, until it was clearly visible externally in all the inoculations. The normal dark green colour of the rind changed to a dirty mottled red, which spread

in vertically elongated streaks and, at the end of the 2nd week, entirely surrounded the node and had extended for an inch or two above and below. After twenty days several inoculated roots were examined at their origin from the stem and large quantities of hyphæ were found passing from the root to the stem, not only along the vascular tissues but also laterally into the stem parenchyma in all directions. Fig. 5 shows the conditions at this stage. The stems were split longitudinally a month after the inoculations and were found entirely infected, the characteristic pith discoloration, with transversely elongated white blotches, being well developed.

Further inoculations were made on June 3rd, 1913, on the feeding roots of well-established cane plants growing in large culture pots in soil. The soil was carefully removed until the roots were exposed and these were inoculated by sprinkling with a suspension of spores from a pure culture, care being taken not to injure the roots. The soil was then replaced. After sixteen days two of the inoculated roots were examined by sectioning. Both showed a small area of reddening 2 or 3 mm. behind the growing point. Penetration was found to have occurred here (Fig. 4) and the hyphæ were extending freely in the tissues of the root.

Out of many hundreds of canes affected with red rot examined during the past ten years, we have met with a limited number of cases where natural infection had occurred through some part of the stem above ground and where the base of the cane was unaffected. In February, 1910, a Khari cane was examined and was found to show definite symptoms of red rot in the 5th and 6th internodes from the base, the lowest internodes being quite free from reddening or hyphæ. At the node between the two infected internodes there was a broken shoot, distinctly reddened in its interior. Characteristic hyphæ of *Colletotrichum* were found in this shoot and could be traced from the broken surface through the bundles into the pith of the stem. There were no other injuries, and infection had doubtless occurred through the broken shoot. A second cane of the same variety showed a similar case of infection through a broken shoot at the 5th node. Higher up several nodes showed slight infection,

which was traced in every case to an infected adventitious rootlet eye. At the 20th node there was another broken shoot, through which infection had occurred. In all these cases, sections taken so as to include the shoot or root and the main stem, enabled the hyphæ to be clearly traced from one to the other. In another case infection occurred through root eyes at the 15th node and also in the 8th internode through a crack in the rind. This is one of the few cases where infection has been found arising from a definite stem wound. The cane was also affected with smut (*Ustilago Sacchari*).

From the above experiments it appears that wounds caused by boring insects, while undoubtedly capable of admitting the parasite should it reach them, are not, in practice, responsible for many cases of red rot in India. Old leaf scars are not readily penetrated, but since infection through the leaf bases has been obtained by Howard, this probably depends on the degree to which abscission has progressed at the time of inoculation. Under normal conditions the leaf scars are not exposed until the leaf has completely withered and, as our inoculations show, such scars are not readily infected. During the process of wrapping, which is common in parts of India, less completely withered leaves are sometimes torn away from the stem, and the scars left in these cases are probably a source of danger. In a few cases the cracks which form in the internodes of some varieties probably admit the fungus. One such case is recorded above. But the commonest points of entry in new infections of the above ground stem, in India, are undoubtedly the shoot and root eyes at the nodes.

THE SOURCE OF INFECTION IN NEW ATTACKS.

We now come to another aspect of the subject and that is the source of infection in those cases in which new attacks occur in the cane stem. Practically all observers are agreed on the comparative rarity of the sporing stage on the surface of diseased cane stems, until these have dried up more or less completely. When we consider the extraordinarily abundant production of spores in most

fungi which depend on the wind for their dissemination and the chances of the individual spore alighting on a susceptible part of the cane stem, this point becomes of significance. But, as was pointed out in 1906, there is another part of the cane on which a fungus agreeing in morphological characters with *Colletotrichum falcatum* is frequently found and produces spores in greater quantity and more exposed to the wind than the stem form. This is the midrib of the leaf. Earlier writers have reported the occurrence of the fungus as a saprophyte on old, withered leaves of sugarcane.[1] That it also occurs not uncommonly as a leaf parasite seems to have escaped the notice of most observers, though Edgerton[2] refers to it. Experiments were carried out at Pusa to determine if the leaf form could infect the stem and conversely.

Three of these experiments have been described above (page 158) where it was shown, firstly, that wound inoculation with a pure culture of the midrib form caused visible infection of from one to three internodes after three months and, when the inoculated canes were planted, red rot developed in them with severity, and, secondly, that inoculation of the setts, immediately before planting, causes just as severe disease as when the stem form of the fungus is used. In another case a pure culture of the leaf fungus was used to inoculate Striped Mauritius cane, 11 inoculations being made towards the base and ten towards the apex of the stem. In a little over two months, 7 of the former were examined and showed 7+3+2+1+0+4+4 internodes affected. In 6 of the canes inoculated towards the apex, 3+1+0+1+1+2 internodes were found diseased after the same period. These experiments show that the leaf fungus can attack the stem and the cut setts, the symptoms produced being those of typical red rot.

The parasitism of the midrib form was next tested on leaves. In the first experiment spores from a pure culture were sown in drops of water on the upper surface of the uninjured midrib of growing canes. Out of 6 inoculations, none succeeded. The ex-

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[1] Went, F. A. F. C. Notes on Sugarcane Diseases. Ann. of Bot. X, 1896, p. 588.

[2] Edgerton, *loc. cit.*, p. 4.

periment was repeated on 4 shoots in the laboratory, kept under bell jars to prevent the inoculated spot from drying rapidly. These also failed. In a third series, similar to the last, 6 inoculations were made without result. A month later, however, out of 12 similar inoculations, 5 succeeded. When the midrib was wounded, much better results were obtained. In the first trial 5 leaves were inoculated in plants growing in tubs in the laboratory, the upper epidermis being first removed by scraping with a sterile knife and the spot, after inoculation, being covered with damp sterile cotton wool to keep moist. All succeeded well, the characteristic red discoloration being well developed by the 9th day. In another series, 4 inoculations were made after injuring the epidermis of the midrib by touching it with a hot knife blade for 2 or 3 seconds. All took the infection severely. Four more were inoculated on another occasion, after scraping off the epidermis, and again all took.

Experiments were next made to test the parasitism of the stem form of *Colletotrichum falcatum* on the leaves. In the first experiment, spores from a pure culture were sown in drops of water on the upper surface of the uninjured midrib of canes growing in a tub in the laboratory. Of 15 inoculations, none succeeded. The experiment was again tried and of 7 inoculations, all succeeded. In a third series, out of 13 inoculations, 5 succeeded. When the midrib was wounded before inoculation the results were as follows. In the first trial 5 inoculations were made after scraping off the epidermis. The inoculated spot was covered with a pad of damp sterile cotton wool. None succeeded, the fungus growing by choice into the cotton wool. A similar experiment at a later date was made on 3 shoots standing in water, no cotton wool being used but the shoots being covered by bell jars. All succeeded. In a third experiment, the epidermis was injured by touching with a hot knife blade and all of 4 inoculations succeeded.

Though both leaf and stem forms, are capable of penetrating uninjured leaves, infection occurs much more readily when the leaf is wounded. The microscopic details of penetration will be described below. In nature, it has been observed that *Colletotri-*

chum is common around the hole which a minute boring insect frequently makes in the midrib. Salmon[1] has found in similar experiments with the mildews (*Erysiphaceæ*) that "green fly" (*Aphis*) has the same effect as a wound, in weakening the resistance of the plant cells to infection.

From these experiments it is apparent that there is no essential difference in the ability of the forms of *Colletotrichum*, found on the living midrib of the leaf and on the stem, to attack stems and leaves of sugarcane. Taken in conjunction with their morphological similarity, they must be held to be the same fungus. The species appears to be confined to sugarcane. The only other *Colletotrichum* resembling *C. falcatum* found widely distributed in India, is *C. Lineola* Corda, which attacks the leaves of jowar (*Andropogon Sorghum*) frequently. Morphologically the two species are closely allied, but the jowar fungus does not attack cane leaves. Out of 16 inoculations, half on unwounded spots on the midrib, half after scraping off the epidermis, none succeeded. Edgerton[2] failed to get symptoms of red rot by inoculating sugarcane stems with this species and also with the allied *C. cereale*. It is probable that many of the new attacks of red rot on the above-ground part of the cane stem, arise as a result of infection by spores blown from the diseased midribs of cane leaves. We do not see how it will ever be possible to avoid this, but it only gives greater force to the arguments in favour of concentrating attention on the elimination of diseased setts at the time of planting.

The actual penetration of the fungus into the tissues was studied in the leaf inoculations. Including both leaf and stem forms, altogether 63 inoculations were made on the uninjured midrib, of which 17 succeeded and 46 failed; while when the epidermis was wounded 20 out of 25 inoculations succeeded. In the successful cases where the epidermis was uninjured, penetration usually occurred not directly into the midrib but by superficial growth of the fungus until the large motor cells lying in groups on either side

[1] Salmon, E. S. Cultural experiments with "Biologic forms" of the *Erysiphaceæ*. Phil. Trans. Royal Society, Ser. B, Vol. 197, 1904, p. 112.

[2] Edgerton, C. W., *loc. cit.* p. 7.

of the midrib were reached ; these were then penetrated (Fig. 1). As is already known, the germ-tubes of the spores readily form appressoria (described under the name of "gemmæ" by Went and of chlamydospores by most other writers). These are thick-walled, durable cells, capable of surviving detachment from the mycelium. It is probable that they serve a double purpose of close adhesion to the surface of the host plant and of accumulation of enzymic energy to secure penetration of its walls. In *Colletotrichum falcatum* the infection hypha seems to arise as a rule from an appressorium (Figs. 1 and 2). Entry through stomata was not observed, the infection hypha passing directly across the outer wall of an epidermal cell, or, in some cases, down between the side walls of two cells. After entry, the hyphæ may at once branch freely and fill the large motor cells with a mass of mycelium, or may penetrate deeply into the leaf, passing from cell to cell with ease in the large-celled parenchyma between the bundles, but not readily entering the latter. In some cases the sclerenchyma was penetrated, but usually, when the leaf had not been injured before inoculation, the hyphæ remained, for the first week at least, confined to the thin-walled cells. In the cases where the leaf was first wounded, conditions were somewhat different. There was a superficial growth as before, extending beyond the limits of the wound. But penetration was not now confined to the thin-walled motor cells but occurred freely into the epidermis of the midrib just beyond the wounded part (Fig. 2), and the mycelium ramified through the sclerenchyma as readily as through the parenchyma. In some cases, the layers of underlying sclerenchyma left after removing the epidermis, were an effective barrier and penetration only occurred beyond the midrib into the thinner tissues between the bundles, but in others, presumably when the injury was more severe, the thick-walled tissues showed much mycelium. All the invaded tissues developed a bright red colour.

In less than a week fructification may occur on the infected spot. The hyphæ first collect, in masses in the epidermis, through

which they then break as stromatic bodies, on which the characteristic spores and sterile hairs are formed.

Relative susceptibility of the top and bottom of the cane.

Experiments were recorded in the previous Memoir[1] to show that much of the damage caused by red rot is due to inversion of the cane sugar. This appears to be because glucose is more readily assimilated by the fungus, growth in solutions in which the sugar was provided as glucose, being invariably better, at least at first, than when cane sugar was supplied. Flasks were prepared with solutions containing 10 per cent. cane sugar and glucose respectively together with peptone and sodium chloride, and inoculated with a loop of a suspension of spores, from a pure culture, in distilled water. The growth in the glucose flasks early took the lead and maintained its superiority for some weeks. More recently, Lewton-Brain[2] has dealt with the same question in considerable detail. He found that the inverting action of the fungus was considerable, but that, as stated in the previous Memoir, the actual consumption of sugar was small. This consumption, he found, fell entirely on the levulose. Thus in one experiment, though 75 per cent. of the sucrose was inverted, not one-twentieth part of this was actually consumed by the fungus and this appeared to be all levulose. The inversion was proved to be due to the presence of invertase, which was found both in the mycelium and also in the solution in which the fungus was grown.

Since it is known that the upper portion of the cane is richer in glucose, though poorer in total sugars, than the lower[3], experiments were made to compare the growth of the fungus in the top and bottom portions. In the first experiment, 3 sound Striped Mauritius canes were cut and brought to the laboratory. They were each inoculated at a lower and an upper internode by removing

[1] Butler, E. J., *loc. cit.*, 1906, p. 7.

[2] Lewton-Brain, L., *loc. cit.*, 1908, p. 32.

[3] Leather, J. W. Chemical composition of sugarcane and raw sugars. Agric. Ledger, No. 3 of 1897, p. 13.

a cylinder aseptically with a small cork borer and inserting a small quantity of a pure culture of *Colletotrichum.* After eight days they were examined. The lower inoculations were found to have infected 2 + 2 + 1 internodes respectively, the upper 1 + 2 + 4. The experiment was repeated with Samsara canes, 6 being inoculated in the same way. After seven days one was examined and was found to have 2 internodes infected at the base and 1 at the top. Two days later another was examined, 5 and 2 internodes respectively being found infected. Two days later the rest were examined. In one the infected portions had united in the middle. In the other three, 11 + 10 + 7 internodes were found infected at the base and 3 + 5 + 2 at the top. The experiment on page 167, where inoculations with the leaf form of the fungus were made at the top and bottom of growing canes, should also be compared. As the practical point at issue was to determine if any recommendations could be made for planting one part of the cane rather than another, where red rot is prevalent, the natural inversion that goes on after cutting was not taken into account, since it must equally go on in planted setts before germination. The experiments do not suggest that tops, though richer in glucose, can be more rapidly invaded by *Colletotrichum* than the rest of the cane and there appears to be no objection to their use from this point of view. The second experiment and that given on page 167, indeed suggest that the contrary is the case. Tops are also less likely to contain the fungus, when it has originated from below at a late stage in the growth of the cane.

CONTROL OF THE DISEASE.

The control of red rot was stated by the earlier investigators to be likely to be very difficult, owing to its position in the interior of the cane, the frequent absence of definite symptoms by which it might be detected in the growing crop and the practical impossibility of preventing wounds which would give an entry to the fungus. But of recent years little has been heard of the disease in Java, where it was first described, and it may be concluded that it has not proved so serious an enemy as was once feared.

In India it is in many places the greatest obstacle to successful cane cultivation. In Madras, Bombay and Bengal the area under thick cane has in certain districts periodically shrunk as a result of an accumulation of red rot in the crop, to expand again only when the diseased cane has been replaced from outside. Red rot has often been the limiting factor to the successful cultivation of heavy yielding canes.

The experiments given above are, we think, sufficient grounds for holding that this should not be the case: that, granted that a start is made with a healthy stock, it should be possible to keep the disease under control with no more than an occasional severe outbreak due to a specially unfavourable season.

The first requirement is to start with a healthy stock. In those districts, such as the Godavari Delta and some parts of Bombay Presidency,[1] where the local canes have become widely infected, new healthy seed must be brought in from outside. The very successful history of the Samalkota Sugar Station in the Godavari Delta, shows what excellent results may be obtained by this measure under efficient supervision. It is highly probable that the little that has been heard of red rot in Java, in recent years, has been due to the efforts made to obtain good cane for planting, from special seed nurseries, combined with the growth of seedling canes which will be referred to below. As the Samalkota results are available in the Annual Reports of the Station, the methods adopted need not be more fully detailed. The past history of the cane must be taken into consideration. There is good evidence to show how dangerous it is to grow a variety from stock known to have been seriously infected, even though the crop may do well for the first few years. Large estates or groups of estates should be self-contained in the matter of seed supply and should possess a nursery or testing garden for the trial of new varieties under the best conditions. For the ordinary native cultivation, Government Farms should be utilized for the same purpose. In this way a supply of

[1] Kulkarni, G. S. Preliminary study of the red rot of sugarcane in the Bombay Presidency. Dept. of Agric., Bombay, Bull. No. 44, 1911, pp. 5-6.

healthy seed can be assured and new varieties can be introduced into cultivation as required.

Systematic and thorough selection of the setts used for planting must then be done each year or the new varieties will not maintain their freedom from disease for long. The methods to adopt are described in a previous paper[1] which should be referred to, and present no difficulties in practice. We consider that there is no single operation in the cultivation of thick canes in most parts of India of greater importance than this. It is not to be anticipated that the disease can be got rid of by a single selection nor, indeed, usually got rid of in its entirety by annual selection : the most that is claimed is that it can be kept within reasonable limits in normal years and with good cultivation. The object of the selection is to prevent an accumulation of red rot to such an extent as materially to reduce profits and render it difficult to obtain a sufficient supply of sound seed for the coming season.

Of lesser importance, but still worth doing in most cases, is the regular removal of all withering clumps during the growing and ripening season. Such clumps, if left, dry up and produce spores, sometimes in considerable quantity. Infection of even perfectly sound cane through the aerial root eyes and through injured buds has been shown to occur and though our experience in Northern India has been that such infection is not common, it is perhaps more frequent in Madras, where the disease appears to be more virulent and rapid in its onset than with us. There is, also, the danger of infection through the soil, especially in irrigated cane, by means of the shed spores.

Judging from Godavari experience it is important to give cane a long rotation. How far this results from the peculiar circumstances of cane cultivation in heavy paddy soils, with very frequent irrigation, is not clear. In the Godavari Delta, the old practice was eight or nine years' rest from cane after a two years' cane crop (one year plant cane and one year ratoon). More recently, it has been reduced

[1] Butler, E. J., *loc. cit.*, 1907.

to six years, probably with bad results.[1] At Samalkota a two years' "dry" rotation (not followed by paddy) and a three years' "wet" rotation (followed by paddy) were tried, but found unsatisfactory. On the other hand, at Pusa, cane one year in five has been satisfactory and the non-irrigated cane in Bihar usually gets a much shorter rotation. The fungus appears to die out rapidly in moist soil, but cultures exposed to the air and kept moderately dry retain their vitality for at least five months. In Hawaii, Lewton-Brain found that plate cultures allowed to dry out invariably gave no sign of vitality after three months. But if cane is present, there seems to be little doubt that *Colletotrichum* lives and spreads through the soil and, in the young irrigated crop, passes from trench to trench, either with the seepage of irrigation water, on the feet and implements of coolies or (though less certainly) by direct growth through the soil. It has been shown that the roots are readily infected and we have lost several series of comparative experiments at Pusa through ground infection of control trenches. Fortunately the radius of spread does not appear to be large and if the measures detailed above are carried out, little injury should be caused in this manner.

In spite of all these precautions, serious attacks of red rot, from circumstances not ordinarily under control, may occur from time to time. We have met with two such cases. One was the outbreak at Pusa in 1907-08, which was, without doubt, the result of an epidemic of cane-fly (*Pyrilla aberrans*) on the cane that year. Leaf-hoppers are well known in other countries to be associated with bad attacks of fungus diseases as, for instance, in Hawaii, where "rind disease"[2] follows with great intensity the epidemics of leaf-hoppers. It is probable that the action of these insects is chiefly to reduce the vitality of the cane and render it increasingly sus-

[1] Wood, R. C. Scientific Report for the Samalkota Agricultural Station for 1908-09. Government Press, Madras, 1909.

[2] The cause of this disease is not yet quite clear. Howard in the West Indies and Went in Java held that it was identical with red rot, the fungus, *Melanconium Sacchari*, previously believed to be its cause, being merely a follower of *Colletotrichum falcatum*. Subsequent workers, such as Lewton-Brain, Cobb and Edgerton in the West Indies, Hawaii and Louisiana, have reverted to the previous view, though quite recently South and Dunlop have failed to establish the parasitism of *Melanconium Sacchari*. In the East, this fungus has not been recorded as a parasite.

ceptible to infection from aerial spores, which were formed in considerable quantity on the leaves during the outbreak at Pusa. The other case was a severe attack of red rot following extensive flooding of the cane fields, in some estates in Bihar several years ago. The effect of unfavourable external conditions such as this on the onset of the disease is discussed more fully below.

SUSCEPTIBILITY OF VARIETIES OF CANE.

Little light has been thrown by these investigations on the question of the relative susceptibility of different varieties of cane to red rot. One fact that is obvious to any observer of the disease in India is that the thin varieties of cane are, on the whole, less susceptible than the thick. Some of the Indian thin canes are so widely divergent from the thick races, that writers in Java have suggested that they may have originated from different species of *Saccharum*.[1] If so, one may perhaps anticipate that the relative immunity of the thin kinds will prove to be a deep seated "germ" character. With regard to the thick canes, certain observers, and in particular Dr. C. A. Barber, hold that the temporary or apparent immunity of certain thick varieties can be broken down by bad cultivation. He describes[2] how, in the Godavari Delta, successive canes have held favour during the past forty years, each in turn growing luxuriantly and bringing wealth, but after a few years becoming diseased. The constitution of each cane had been broken in turn by the ever-present fungus, until all the plants of that kind in the district were infected. Again he states[3] that of the varieties of cane brought from other countries for trial at Samalkota, none were really immune and it is probable that ultimately all will succumb in turn when placed under the adverse conditions of the local agriculture. In the same paper[4] he mentions as a curious fact that the Hospet cane varies greatly in its liability to disease in the different regions where it is found. A similar case occurred with the

[1] Kobus, J. D. Overzicht van het verloop der importatieplannen van vreemde rietsoorten op een eiland buiten Java. Archief v. d. Java-Suikerindustrie, II, 1894, p. 662.

[2] Barber, C. A. The Samalkota Sugarcane Farm. Agric. Journ. of India I, 1906, p. 45.

[3] *Ib.* Seedling canes in India. Agric. Journ. of India, VII, 1912, p. 324.

[4] *Ib.* *loc. cit.* p. 329.

Bombay Pundia cane which, when introduced at Samalkota, went out from disease in the first season, though the parent stock is little subject to red rot. Kulkarni[1] also notes the gradual deterioration of thick canes in parts of Bombay, and West Indian literature is full of references to the breaking down in health of the Bourbon cane, once widely grown, and this breaking down seems to have gone on more rapidly in some localities than in others.

These experiences with sugarcane are by no means unique amongst plants ordinarily propagated in a vegetative manner, that is by tubers, cuttings and the like. In Ireland the "Champion" potato was largely cultivated for many years, on account of its resistance to potato blight, but it has lost its resisting powers and been replaced by newer "seedling" varieties. Several similar cases are known, and the phenomenon is of considerable scientific interest.[2] Such progressive deterioration is in many cases apparently innate and has been likened to senescence, being capable of being checked when a new generation is started by sexual reproduction (*e.g.*, by raising from seed). But it can be hastened by exposure to unfavourable conditions or, on the other hand, be postponed by profound change in the environment. Barber states[3] that the surest way to induce red rot in cane to make its appearance is to plant the canes in a water-logged site. Harrison, in British Guiana, considers that the susceptibility of certain kinds of plants for instance, the Bourbon cane, to fungus attacks is due in part at least to defective soil conditions.[4] Such statements can be multiplied and must, we think, indicate a real phenomenon. In the opposite direction are such cases as that recorded by Calkins,[5] where a constantly changing culture medium was found to have the effect

[1] Kulkarni, G. S. Preliminary study of the red rot of sugarcane in the Bombay Presidency. Department of Agriculture, Bombay, Bull. No. 44, 1911.

[2] c. f. Hartog, M. Problems of Life and Reproduction. *Progressive Science Series*, 1913, p. 19.

[3] Barber, C. A. The Samalkota Sugarcane Farm. Agric. Journ. of India, I, 1906, p. 45.

[4] Harrison, J. B. Varieties of Sugarcane and Manurial experiments in British Guiana. *West Indian Bulletin*, IX, 1909, p. 36.

[5] Calkins, Gary N. Protozoology, 1910, p. 109.

of prolonging the life of the race in Protozoa, bred from a single individual and not permitted to conjugate; when asexual propagation only is allowed and the environment kept constant, the race soon degenerates and dies out.[1]

It is not unlikely, therefore that there are two types of relative immunity, a genetic, such as is shown by the thin canes so widely cultivated in India, and a fluctuating, and that the latter is much more exposed to the influence of external conditions than the former. Indian thick canes, which have been subjected to vegetative propagation without a break for many generations, seem to show no evidence of genetic immunity. Hence frequent change of climate, good cultivation and good hygienic conditions generally, seem to be of great importance in preserving them from epidemics of disease.

The possession, by India, of a large range of relatively immune (to red rot) thin canes, of hardy habit and great tillering powers, though less productive than the thick canes of other countries, may prove an asset of the greatest value. The growth of seedling canes has been recently undertaken at the Coimbatore cane-breeding station under the control of Dr. Barber. If it is found possible by hybridization to combine the resistance of some of the thin canes to red rot, with the yielding qualities of a thick cane, a great step forward in enabling India to grow enough sugar for her own consumption and perhaps even to compete successfully with the sugar exporting countries, will have been taken. It is a happy augury that amongst the best of the canes now grown in Java (the most formidable competitor in sugar production that India has to meet) are the progeny of crosses between an Indian thin cane, the "Chunnee" obtained from Shahjahanpur (where, Dr. Barber informs us, it is locally called Chin), and the Cheribon thick cane grown in Java.

PUSA,
June 30th, 1913.

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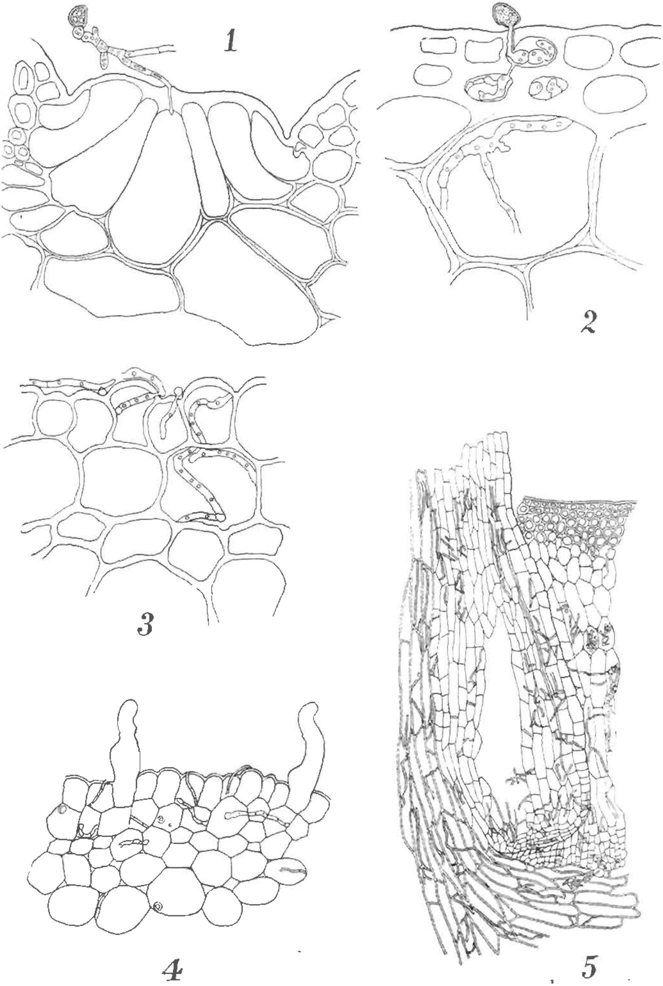
[1] Since this was written a very illuminating discussion of the deterioration of sugarcane varieties after long-continued vegetative propagation, written by Harrison, Stockdale and Ward (West Indian Bulletin, XIII, 1913, p. 177), has been received.

PLATE



Infection of sugar cane leaves and roots by the red rot fungus.

DESCRIPTION OF THE PLATE.

Fig. 1. Penetration of a hypha, arising from an appressorium of the stem form of *Colletotrichum falcatum*, into a motor cell of the unwounded leaf of sugarcane. The midrib commences immediately on the right of the figure. X 350.

Fig. 2. Penetration of a hypha, arising from an appressorium of the stem form of *Colletotrichum falcatum*, into a cell of the thick-walled part of the epidermis at the edge of the midrib of the sugarcane leaf. The neighbouring central part of the midrib had been wounded by scraping off the outer layers with a sterile knife. X 500.

Fig. 3. *Penetration of an adventitious root on the stem of sugarcane by hyphæ of Colletotrichum falcatum, through the uninjured epidermis.* X 500.

Fig. 4. Penetration of an underground root of sugarcane by hyphæ of *Colletotrichum falcatum*, through the uninjured epidermis. X 300.

Fig. 5. Passage of the mycelium of *Colletotrichum falcatum* from a young inoculated adventitious root, of the same series from which fig. 3 was drawn, back to the main stem of the sugarcane. The hyphæ enter the vascular tissue and the parenchyma of the stem and spread in all directions. X about 50.

SOME NEW SUGARCANE DISEASES

BY

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I.—Wilt.

(*Cephalosporium Sacchari* Butl. n. sp.)

In the course of investigations of the red rot of sugarcane, caused by *Colletotrichum falcatum* Went, a second disease, to which the name red rot might equally well be applied, since it produces distinct reddening of the cane pith, has frequently been encountered. With a little practice the two diseases can be distinguished and they are caused by entirely distinct organisms.

As in red rot, the earlier symptoms are elusive. Except in such cases of severe infection of the cuttings selected for planting as cause the death of the young shoots, in the manner more fully referred to below, little is noticed until the cane is about half grown. At this period affected canes lag in growth and stunted, single stools, or patches of varying size, may soon be observed scattered through the fields in which the disease is prevalent. From this on until the time of harvest, withering of individual canes, or even of whole stools, occurs. The leaves dry up, as if insufficiently supplied with water, followed by the stems, which become light and hollow. If the cane be split longitudinally when the leaves are first observed to wither, a charac-

teristic discoloration of the pith, as shown in Pl. I, Fig. 1, may be observed. A comparison of this figure with a coloured drawing of true red rot will show the difference in appearance of the two* diseases. Instead of *bright red patches and streaks, broken by* transversely expanded white areas, there is a diffuse purple or dirty-red colouration, in which brighter red, vertical lines mark the position of the bundles. The tendency of the colour to become muddy at an early period is its most strongly marked character and serves to distinguish the disease from any other known to us. In old cases the red almost disappears, being replaced by an earthy brown. The pith dries up more rapidly than when attacked by *Colletotrichum* and becomes hollow. Within the hollow portion, a fluffy grey growth of mould is often found.

Microscopic examination shows that the stem is infested throughout the reddened portion, which may be confined to a few joints or extend to the whole length of the cane, by a fungus, whose hyphæ ramify through the cells in all directions, penetrating the fibro-vascular bundles as freely as the large-celled parenchyma of the pith (Pl. II, Figs. 2 and 3). Most of the hyphæ are fine, not exceeding 3 μ in diameter in recently infected parts, and either uniform or tapering gradually. They pass from cell to cell through the pits in the walls, when pits are present (Fig. 2), but can also penetrate unbroken walls and seem to have no preference for one tissue more than another. Even when old, they remain hyaline. Occasionally they have been found bearing conidia in the vessels (Fig. 5) and possibly do so also in the parenchyma of the pith, as the condition shown in Fig. 4 appears to represent an early stage of spore-formation. The conidia are small, hyaline, unseptate, oval, and usually appear to be borne singly on short lateral branches of the mycelium. They resemble closely the microconidia frequently found in the vessels of plants affected with the *Fusarium* wilts.

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* See Memoirs, Dept. of Agric. in India, I, No. 3, 1906, Pl. I, or Agric. Journ. of India, II, 1907, Pl. XI.

In the hollow which invariably forms in the pith of affected internodes at a late stage in the disease, there is usually a copious greyish-white, fluffy growth of hyphæ, similar to those found in the tissues, and bearing great numbers of conidia, resembling those observed in the vessels, though often of somewhat larger size. The characters of the fungus can be studied from this growth or, more satisfactorily, from pure cultures, and they show it to be a member of the form-genus *Cephalosporium*. several species of which are known to be lower stages in the development of *Hypocreaceæ*.

The hyphæ are hyaline, slender (about 3 to 5 μ in diameter), richly branched, sparingly septate when young, not varying abruptly in diameter, though swollen segments are found in old cultures. Sometimes the individual filaments unite together to form coremial strands, usually only two or three hyphæ taking part in the formation. An early stage of such a strand is shown in Fig. 6a. Chlamydospores have not been observed either in culture or in diseased canes.

The conidia are borne on short, simple or branched, lateral hyphæ and also terminally on the ultimate branches of the mycelium. They measure 4 to 12 μ (usually 5 to 8 μ) by 2 to 3 μ, when formed, but increase in size prior to germination. Their shape varies from shortly oval to ovoid or long elliptical. Occasionally they are curved or with one side flattened. They are almost invariably unicellular when formed, but some become septate prior to germination, the septa being 1 to 3 in number (Fig. 11). Spores and mycelium are hyaline.

The conidiophores are usually of definite shape, measuring from 6 to 30 μ by 3 to 4 μ at the thickest part, swollen slightly in the middle or lower third, narrowing below where they arise from the mycelium and tapering above, but with an obtuse apex on which the spores are borne (Fig. 7). They may be scattered along the hypha or arise in bunches near together (Fig. 6). Branching is not uncommon, being irregular or once whorled or forked. Each branch usually bears conidia at the apex, but if kept very moist the branches may grow out into long hyphæ.

The first conidium is borne at the tip of the conidiophore and, when full grown, is pushed to one side by the formation of a second spore at the same point, and so on until a number have been produced. Sometimes, instead of forming a second spore, the apex continues growth as a hypha, which may again bear conidiophores (Fig. 13*a*). Unlike most members of the genus, the successively formed conidia are not held together in a mucilaginous drop, but adhere merely by surface attraction and are very easily dislodged. If kept free from currents of air in a moist chamber, heads of 5 or more can readily be found. They adhere more firmly at the base than elsewhere and if carefully mounted, after treatment with acetic acid, such appearances as those figured in Fig. 7*a* can be observed. At first sight this suggests that the spores arise near together and at the same time, as in the genus *Haplotrichum*, but more careful examination shows that this is not the case, only one spore being formed at a time and the whole apex of the conidiophore taking part in its formation. The apex is pushed out by growth from within the hypha to form the spore, and if examined just after the latter has fallen and before a second appears, the condition shown in Fig. 9 is found. In moist-chamber cultures spores formed on the aerial mycelium appear as shown in Fig. 8, lying in a single layer with their long axes parallel. Spore-production is extraordinarily copious, almost every hypha being abundantly provided with conidiophores throughout the greater part of its length.

Germination occurs within 24 hours in many cases, the large septate and small unseptate conidia behaving in much the same manner (Fig. 11). The germ-tube is usually single and terminal, but the septate spores may give out a tube from each end. Union of two or more germ-tubes, belonging to different spores, is common (Fig. 12), up to five spores having been found united in this manner. One or two of the germ-tubes grow out into strong hyphæ from the united mass, the arrangement being probably merely a nutritional adaptation.

In culture on nutrient agar the mycelium remains white and filamentous and no formation of stromata or of other types of

spores has been observed. The species does not agree with any previously described and has been named *Cephalosporium Sacchari*, the diagnosis being as follows :—

Cephalosporium Sacchari Butl. n. sp. Effusum, candidum ; hyphis repentibus, parce septatis, 3-5 μ diam. ; conidiophoris continuis, simplicibus furcatis vel subverticillato ramosis, sursum obtusis, medio vel versus basim incrassatis, 6-30 μ long. 3-4 μ crass.; conidiis ex apice ramulorum pluribus continuis exsilientibus et in capitula collectis sed facillime secedentibus, hyalinis, ovoideis vel oblongo-ellipsoideis, continuis, 4-12 ✕ 2-3 μ.

In culmis *Sacchari officinarum* in India or

Cultures of the fungus can be readily obtained in the same way as with *Colletotrichum falcatum*, by cutting out aseptically a portion of the pith, in the early stage of the disease, and incubating in a sterile Petri dish or potato tube. The growth is frequently pure from the commencement, but if not, can be readily purified by sub-culturing from the aerial mycelium. The following inoculations were carried out with pure cultures from nutrient agar, in which spore-production was copious.

On December 13th, 1908, 20 strong sound Red Mauritius canes were inoculated in a stem wound with a suspension of spores and mycelium in distilled water, from a culture two weeks old. The inoculations were made in the lower half of the cane by removing a cylinder of pith with a small sterile cork borer, inserting a drop of the suspension, and replacing the cylinder after cutting off a little of the end, so as to leave a small cavity. The wound was then bound with sterile gutta-percha sheeting.

The canes were examined after 3 months. In one case only had the whole cane dried up, the infection extending above the wound to the top of the cane, and below for 3 internodes. In the others infection had progressed through from 4 to 6 internodes. The inoculated internode had become hollow in every case, those above and below being also hollow in some cases. The symptoms were typical and the fungus was found throughout the discoloured parts.

On the same day 15 canes were inoculated at leaf scars, the scar being covered after inoculation with a wad of damp sterile cotton-wool, bound with gutta-percha sheeting. The same material was used as in the last experiment.

These inoculations also succeeded, distinct reddened bundles being found after 3 months, extending downward from the scar through the next internode. The progress of the infection was less than in the last case and could not be traced beyond the one internode. The hyphæ were found chiefly in the reddened bundles and there was not much lateral spread. It was noticed that shoots arising from the inoculated nodes were not infected.

The fungus cannot penetrate the unbroken rind of the internodes. Sixteen inoculations were made to test this. a drop of the suspension being placed on the rind, and covered with damp sterile cotton-wool for 48 hours. In no case was there the slightest sign of infection.

As in *Colletotrichum falcatum*, however, the adventitious root eyes at the nodes can be inoculated successfully. Ten inoculations were made on the uninjured eyes, in exactly the same way as in the last experiment, except that the cotton-wool was removed after 36 hours. The first sign of success was noticed after 4 days; one of the eyes being slightly discoloured. On sectioning, the hyphæ were found to have penetrated through the epidermis and to have reached almost to the centre of the bud. Three days later all the inoculations had clearly succeeded, the eyes being reddened and full of hyphæ. After 10 or 11 days the eyes were quite killed and the hyphæ were passing into the main stem.

To see if the cane can be infected through the setts at the time of planting, half a trench of Striped Mauritius was planted on March 7th, 1907, after dipping the cut setts in a suspension of spores and mycelium in distilled water. The remaining half trench served as control. Germination was approximately equal in the two halves, but 22 shoots withered in the inoculated half up to June 17th, whereas there were only a few deaths in the other

half, apparently due to white-ants. The *Cephalosporium* was recovered from 3 of the withered shoots examined.

As this fungus has been several times found associated with *Colletotrichum falcatum*, experiments were made similar to the last, but with mixed suspensions of the two fungi, in 1907. The results were striking. Germination was good in both halves of the trench, but 45 shoots withered in the inoculated half in the first three months, while there were very few failures in the rest of the trench. *Colletotrichum* was recovered from 2 of the withered shoots and *Cephalosporium* from 8, out of 14 examined. The experiment was repeated in 1908 with much the same result.

These experiments show that the fungus can enter the cane through wounds, through the uninjured root eyes at the nodes, and through the planted setts. In true red rot the writers have shown* that the latter is the most frequent method of infection in Northern India. In the present case the evidence is not so complete, but it has been found that wound infection is far more common than with *Colletotrichum*. The wounds examined have been all borer holes, which are much the most frequent wounds in standing cane. Altogether 27 have been examined by incubating an aseptically removed slab from just beyond the margin of the hole and, of these, 15 have given the fungus. Out of 9 examined in the 1908 crop when nearly fully grown, 8 were infected. This was the year when the most widespread attack of *Cephalosporium Sacchari* was observed at Pusa.

The disease is found over a large part of India. It has been observed at Surat, Poona, Samalkota and throughout North Eastern India. As a rule it seems to accompany red rot, quite a considerable percentage of the cases examined being due to mixed infection. In the 1908 attack at Pusa, however, there was practically no true red rot and a good deal of damage was done by an unmixed attack of *Cephalosporium*. Similarly, in 1912, several cases of pure infection were encountered, and pure cultures were obtained direct from the mycelial growth in the

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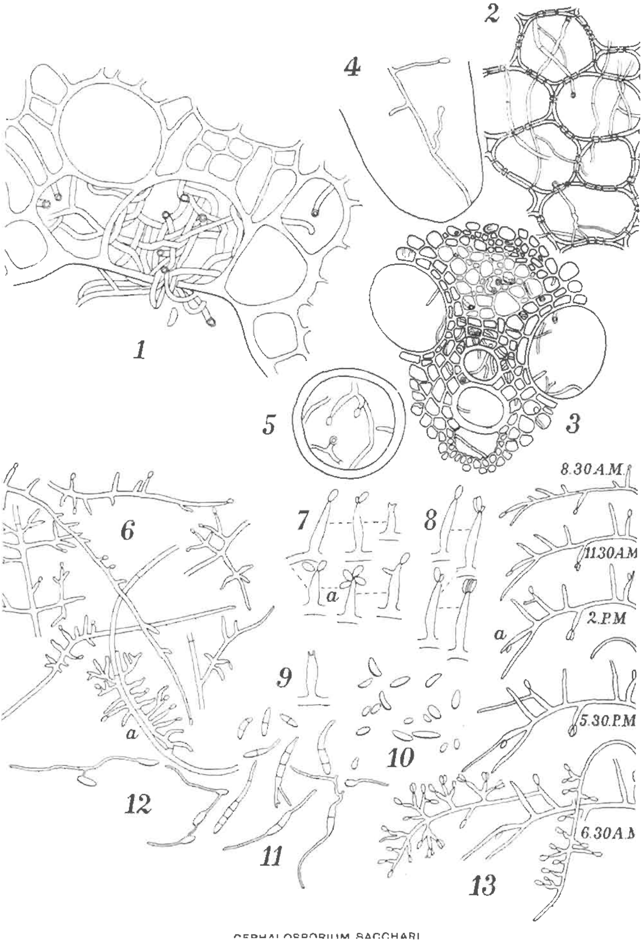
* Butler, E. J., & A. Hafiz Khan, Red Rot of Sugarcane. Mem. Dept. of Agric. in India, Bot. Ser., VI, No. 5, 1913.

hollows of the pith. As a rule, so far as has been observed, the infection is not virulent; spread within the cane is gradual and communication from one plant to another slow. A large number of borer holes become infected late in the season, but the parasite usually seems to remain confined to a few internodes. As bored setts are usually discarded at planting time, infection by this channel is not often transmitted to the following crop. The fungus has not been found on the leaves or on the surface of the stem, in the field. In the laboratory, however, a case of spontaneous infection of the leaf with a fungus exactly resembling that under consideration occurred, and this led to further examination. Inoculations were made with cultures obtained from the growth on the leaf and also with cultures from diseased cane stems. Both gave similar results. Six inoculations were made with each of the two cultures. In two cases the inoculated leaf withered too rapidly to allow of definite observations. The remaining ten were quite successful, Pl. II, Fig. 1, showing the condition after three days. Penetration had occurred chiefly through the large thin-walled motor cells. We have not been successful in finding cases of leaf infection in the field, but as leaf spots are extremely common on sugarcane such a search is not easy. The spot caused by *Cephalosporium Sacchari* in artificial inoculations resembles that caused by *Helminthosporium Sacchari*, described in a later section of this paper, and all the field cases examined belonged to this latter fungus.

Rotten canes must set free large quantities of spores and the source of the infection of cane wounds may come from these, from the leaves and, if the species passes part of its life as a soil saprophyte, as is not improbable, possibly also from the soil. The genus is so common in cultivated soils, and this species has so little to distinguish it from some of the habitual soil dwellers, that its recognition would be difficult. It lives very readily as a saprophyte, however, growing luxuriantly on most of the common culture media and remaining alive in culture for about 3 months, so that it is probably present in the soil of cane fields. The inoculation experiments indicate that infection of the setts at the



CEPHALOSPORIUM SACCHARI

time of planting, causes a good many of the young shoots to wither within the first 3 months. As this early withering has not been very frequently observed in natural attacks, we conclude that infection of the growing cane, through wounds and through the root buds at the nodes, is the more common origin of the disease.

The control of the disease should evidently be on much the same lines as in ture red rot*. As, however, wound infection is far more common, the importance of removing diseased clumps before they have time to rot and set free spores is much greater. As a rule the disease is not a severe one and though our experience with it is limited as yet, it is probable that it is incapable of doing permanent damage so long as the measures advocated against red rot, which we consider to be essential to the successful growing of thick cane in Northern India, are carried out.

Description of Plate II.

(*Cephalosporium Sacchari* Butl.)

Fig. 1. Leaf of sugarcane inoculated with *Cephalosporium Sacchari*, showing fungus in the motor cells and emerging to the surface. × 640.

,, 2. Hyphæ in parenchyma of stem and passing from cell to cell through the pits in the walls. × 190.

,, 3. Hyphæ in fibro-vascular bundles. × 190.

,, 4. Hypha in a cell of the parenchyma with indications of spore formation. × 320.

,, 5. Spore formation on hyphæ in a vessel of the stem. × 320.

,, 6. Mycelium bearing conidia, from a pure culture on nutrient agar. At *a* the commencement of the formation of a coremial strand is seen. × 320.

,, 7. Conidiophores from a pure culture, after treatment with acetic acid. At *a* the adherence of the conidia at their bases is indicated. × 640.

,, 8. Successive stages in conidial formation, drawn from a continuous observation. × 640.

,, 9. Conidiophore immediately after a spore has fallen and before a new one has commenced to appear, showing the hollowed apex. × 640.

,, 10. Conidia from nutrient agar culture, 6 days old. × 640.

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* Butler, E. J., & A. Hafiz Khan, *loc. cit.*

Fig. 11. Germination of the conidia, showing especially the septation which sometimes precedes germination. × 320.

,, 12. Union of the germ-tubes of the conidia. × 320.

,, 13. A spore-bearing hypha continuously observed, showing the extent of growth and spore formation in 22 hours. At *a* conidiophores have continued apical growth after forming a single conidium. The septa have been omitted.

II.—Collar Rot.

(*Hendersonina Sacchari*, Butl. n. g., n. sp.)

In the last section a disease was described which has frequently been mistaken for red rot. A second disease is sometimes confused with red rot in India, and the following description may lead to its recognition and thus secure further information regarding its distribution and the amount of injury it causes the crop, points on which our observations are incomplete.

Towards the end of 1908, a number of canes withered at the Samalkota Sugarcane Station, following on a cyclone at the end of September, which did much harm to the crop. A recrudescence of red rot was feared, as many of the canes were reddened at the base. We examined the crop in January, 1909, and found extremely little true red rot. Some of the damage was apparently not caused by disease but by injury to the root system as a result of the storm. A good many cases were seen, however, in which the symptoms suggested the action of a definite parasite at the base of the plant, and a fungus was isolated from the tissues in these cases which proved capable of reproducing the disease.

In the following season the disease reappeared and was more fully studied, but for the last three years there have been no further records of its occurrence on this farm. Recently it has been found at Jorhat Farm in Assam, and it is possible that it also exists in the Central Provinces, where we have observed a somewhat similar condition, but without being able to make a detailed examination. It has not been recorded elsewhere, and the parasite differs so widely from any previously known that it has been necessary to make it the type of a new genus. The varieties of cane so far observed to have been attacked are Red Mauritius, Striped Mauritius and B. 208.

The symptoms outwardly resemble those of red rot, so far as the withering of the top is concerned. The top leaves wither back from the tip along the edges, the midrib remaining green later than the rest of the leaf. The larger leaves below the crown appear to suffer first, those at the apex remaining unaffected for some time. When the leaves have fully withered, the cane is found to be much lighter than normal. On splitting, the upper part is usually pithy and dry in the centre, or even with a central cavity along each internode, around which the pith is dry, white and flaky. Lower down the pith may be still juicy but has a curious translucent watery appearance; still lower the centre portion may be brown, while red streaks or patches may often be seen, especially at the nodes (Pl. I, Fig. 2). At the base, where the feeding roots arise, the red colour predominates and is especially visible at the nodes. In old cases the lower internodes also dry up and may develop a central cavity, surrounded by red or brown pith. The roots arising from the basal nodes are usually blackened and rotten, and the appearance suggests that the disease enters the base of the stem from the roots.

In the Jorhat cases the buds at the lower nodes had sprouted and subsequently withered. The reddening was specially well developed at the nodes from which these shoots arose. It is not yet certain how far this sprouting of lateral buds is a symptom of the disease, as it appears possible that the Jorhat attack is complicated by the occurrence of a non-parasitic, *sereh*-like degeneration of the cane, which requires further investigation.

Microscopic examination shows that the roots and base of the stem are invaded by a fungus. The mycelium is confined to the definitely reddened parts, being absent from the translucent upper portion of the cane. In the Jorhat cases the fungus was found collected chiefly at the nodes, the intervening internodes being almost free from hyphæ until a late stage. The discoloured roots always contain a considerable quantity of mycelium. In the early stages the hyphæ run between the cells in the intercellular spaces. Here they are usually extremely fine, though thick ones sometimes occur. Later on, branches from the inter-

cellular mycelium penetrate the walls to enter the cells. All the tissues are invaded, bundles as well as parenchyma (Pl. IV, Fig. 1) In the cells, and especially in the vessels, very thick hyphæ may occur, sometimes almost alone, sometimes intermingled with the fine filaments. Careful observation shows that both kinds belong to the same mycelium and can be found in direct continuation with one another. Sometimes a haustorium-like, branched mass, arising from thick hyphæ in an intercellular space, almost fills a cell. At first septation is rather scanty, but in the older hyphæ the septa lie very close together, the segments thus formed being often broader than they are long. No trace of spore-formation was found either in the tissues or on the surface of the diseased canes before their death.

Cultures of the fungus were obtained in the usual way, from the surface of the cane pith cut with a red-hot knife. The fungus grew well on ordinary nutrient agar, forming a dense superficial growth. The following description is from pure cultures on this medium.

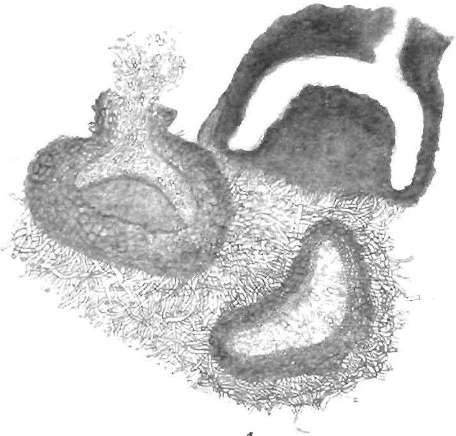
The mycelium is white or faintly tinged yellow. The hyphæ (Pl. IV, Figs. 2 & 3) are very variable in size. The main branches are very thick, sometimes up to 15 μ in diameter, at first hyaline and sparingly septate, then pale yellowish and closely septate. Branching is copious and often rectangular. Very noticeable is the tendency of the older branches to give off extremely fine, hyaline, thin-walled hyphæ, the difference in diameter being so great as to suggest a distinct mycelium, until carefully examined. The thin hyphæ are often irregularly swollen or even nodular and measure sometimes as little as 1 μ in diameter. Anastomosis of neighbouring branches is not uncommon (Pl. IV, Fig. 3*a*). Intermediate stages, consisting of hyphæ 6 to 8 μ in diameter, freely septate when old and often irregularly swollen, are common. The thicker branches break up readily into chlamydospores (Pl. IV, Figs. 4 & 5), which may be terminal or intercalar, and are usually arranged in short chains. They consist of thick-walled cells filled with reserve material, round, oblong or long elliptical in shape, variable in size, the

largest up to 33 μ in diameter, at first hyaline but later slightly coloured. They frequently separate from the mycelium when mature, and may be found lying singly or in short chains intermingled with the hyphæ. They germinate in water by an outgrowth of the endospore. The nodular swellings on the smaller hyphæ seem to be of the same category, but do not usually become detached; they often give off fine branches after reaching maturity. In many cultures no other spore form was found. In several, however, a pycnidial stage developed, and this stage was subsequently found on the surface of old canes which had been killed by the disease.

When pycnidia were formed, they began to appear in about 3 weeks after sowing the tubes, as fine blackish dots immersed in the white mycelium. These grew to form prominent black nodules, which, under the microscope, were found to consist of stromatic tissue with one or more sporiferous loculi entirely immersed in the stroma.

The stromata are leathery, roundish-conical, about 1 to 2 mm. in diameter, and consist of an outer portion of brown, fibrous tissue, composed of closely woven hyphæ, and an inner, bounding the loculi, of dark brown pseudo-parenchyma, many layers deep. Sometimes bands of the fibrous tissue separate the loculi, each cavity then having its separate investment of pseudo-parenchyma (Pl. III, Fig. 1), in others the whole centre portion of the stroma is cellular and the cavities have no distinct walls, except the lighter coloured layers from which the spore stalks arise. The cells of the pseudo-parenchyma are distinct, angular, isodiametric in the deeper layers, but becoming more elongated as the hymenium is approached, with unthickened but deeply pigmented walls and oily contents, and measuring up to 10 μ in diameter. The colour gradually becomes lighter towards the spore-bearing surface.

The pycnidial loculi are deeply sunken in the stroma, very irregular in shape, and often communicate with one another by narrow passages. Every stage may be found between stromata with a single loculus, through such cases as shown in Pl. III,



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Hendersonina Sacchari.

Fig. 1, which we take to represent the union of several unilocular stromata, to truly multilocular pseudo-parenchymatous masses. The cavity is usually narrow, due to cushion-like projections of the wall into the lumen. In small unilocular stromata, the cushion arises usually at the base, the cavity being convex outwards. In larger stromata cushions may also project from the sides, leading to very irregular formations. In transverse section through the middle of the stroma (Pl. III, Fig. 3), the cavities are quite irregular in position, but near the apex the arrangement may be roughly circular, due probably to several loculi converging to a common opening. Laterally situated loculi may, however, open by separate orifices. In longitudinal section (Pl. III, Fig. 2), there is no uniformity of disposition or size of the cavities. The mouth is formed late and is usually not prominent.

The spores are of two kinds, both borne on exactly similar sporophores. The latter arise from the innermost layer of the pseudo-parenchyma, which is not sharply marked off as a hymenium but consists simply of small, rather elongated cells, light yellow in colour (Pl. IV, Fig. 6). From these one or more hyaline sporophores arise and project into the cavity. Usually the sporophore is branched, the branches arising chiefly near the base and each terminating in a single spore (Pl. IV, Figs. 7 & 8). In some stromata unbranched sporophores predominate (Pl. IV, Fig. 9). Septa occur sparingly and the ultimate branches are always slender and unseptate. Each sporophore appears always to bear only one kind of spore, but as they are closely crowded at the base, and both spore forms are found side by side in the same cavity, it is difficult to be certain on this point. Both kinds of spores appear to arise simultaneously.

The most highly differentiated spore form (Pl. V, Fig. 1), consists of brown, elongated cells, rounded at the ends, unicellular or with one or two transverse septa, usually straight but sometimes curved, the curvature in bicellular spores being occasionally sigmoid. They measure $15\text{-}24 \times 3{\cdot}75$ to $5\,\mu$. In some cultures unicellular spores predominated, in others bicellular. Three-celled spores are the least numerous. Germination occurs

in less than 24 hours by an outgrowth from one or both ends, the germ-tube remaining unseptate until it has reached a considerable length (Pl. V, Figs. 4 & 5).

The other spore form (Pl. V, Fig. 2), consists of hyaline filamentous cells, usually without septa but with many oil drops, straight or irregularly curved, variable in length and breadth, the longest being often very narrow, sometimes broader at the base and tapering to a narrow apex, sometimes quite uniform in diameter. They measure 20 to 60 by ·6 to 2 μ. Germination was not observed.

An intermediate form of spore (Pl. V, Fig. 3) is sometimes found, consisting of pale yellow, elongated, 1-septate cells, borne on sporophores of the type above described and measuring 18 to 30 by 2 to 3·75 μ.

After the pycnidial stage had been obtained in pure cultures, it was found in two cases on old canes attacked by the disease, one being an inoculated cane at Pusa, the other a diseased cane from Jorhat. The stromata develop in the internodes, under the epidermis, or one or two layers deeper in, and are smaller than those obtained in culture. The outer fibrous layer is absent or reduced, the mass of the stroma being parenchymatous. The base is broad and extends for some distance all round, as a narrow stromatic layer between the tissue cells. In the centre, the epidermis is raised up and ruptured by the roughly conical, deep portion of the fruit body, which is hollowed out into one or several cavities. Unilocular stromata are common, the cavity being irregular or sometimes imperfectly divided by incomplete walls. The mouth is usually single and develops late. Both spore forms occur in the loculi.

There is much greater uniformity in the spore characters in any one culture of the fungus, than would appear from the above description, which is based on the examination of a large series. Thus, in some cases, the first spore form was almost entirely unseptate and small and the second broad and distinct; in others bicellular spores of the first type were chiefly found, intermingled with which were a few hyaline, attenuated spores of the second

type ; in others again the narrowly filiform second type predominated, while there were numerous "*intermediate*" *spores* and only a few typical bicellular brown spores ; finally in some cases, especially in the earlier cultures, all the types above described, except the "intermediate," were found, though 3-celled spores were never common.

Hence we have had some difficulty in deciding whether the fungus should be considered to belong to the sections *Phæodidymæ* or *Phæophragmiæ* of the *Sphærioidaceæ*. But the characters as a whole agree better with those of the latter section, of which *Hendersonia* is the main type, than with the former, which consists mainly of *Diplodia* and its allies, and the 3-celled brown spores should, we think, be considered as the most highly differentiated and, therefore, most important for systematic purposes. The genus differs from the rest of the *Phæophragmiæ* chiefly in the characters of the stroma and the possession of two distinct types of spore in the same loculus. The latter peculiarity approaches it to the genus *Phomopsis* amongst the *Hyalosporæ*, and it is of great interest as supporting the view that the hyaline, filamentous bodies of the latter genus are true spores, and not merely disjuncted basidia as has been maintained by some observers. There cannot be the smallest doubt that these bodies in the present fungus are spores, for they are borne on true sporophores, in an exactly similar fashion to the spores of the first type. Another fungus in which two spore forms are found in the same pycnidium is *Fusicoccum viticolum* Red*. ; which Shear† has shown to be the imperfect form of *Cryptosporella viticola* Shear. Shear distinguishes the two spore forms as pycnospores and scolecospores, and believes the latter to be true spores, not basidia as held by Reddick. The pycnidia themselves are immersed in a stroma, which is evidently of much the same type as that of the sugarcane fungus.‡ It should be

* Reddick, D. Necrosis of the grape vine. Cornell Univ. Agr. Expt. Stat. Bull. 263, 1909.

† Shear, C. L. The ascogenous form of the fungus causing dead-arm of the grape. Phytopathology, I, 1911, p. 116.

‡ Gregory, C. J. A rot of grapes caused by *Cryptosporella viticola*. Phytopathology, III, 1913, p. 20, fig. 1.

noted that several species described as *Phomopsis* are multilocular stromatic*, though Diedicke, who has most fully studied the genus, places it amongst the simple forms, and does not seem to include any species with a multilocular stroma. Another genus which may be compared is *Endothiella* Sacc., where the bodies described as filiform basidia or pseudo-paraphyses are probably scolecospores.

The following is the diagnosis :—

Hendersonina Butl. nov. gen. *Sphæropsidacearum*—Stromata innato-erumpentia, atra, coriacea, parenchymatice contexta. Pycnidia (loculi) immersa, inæqualia, ostiolis sæpe confluentibus. Basidia ramosa. Sporulæ in basidiis acrogenæ, alteræ fuligineæ, ellipticæ vel elongatæ, rectæ vel curvulæ, continuæ vel 1-2 septatæ, alteræ hyalinæ, filiformes, rectæ vel flexuosæ, continuæ.

Hendersonina Sacchari Butl. n. sp. Stromatibus cortice innatis demum erumpentibus, subgloboso-conicis, 1-2 mm. diam., atris, intus 1-pluri-locularibus ; loculis irregularibus, subinde incompletis vel inter se communicantibus, ostiolis sæpe confluentibus; contextu brunneo, minute parenchymatico ; basidiis ramoso-fasciculatis, hyalinis ; sporulis dimorphis, aliis fuligineis, rectis vel curvulis, ellipsoideis vel elongatis, utrinque obtusis, continuis vel 1-2 septatis, 15-24 ⩔ 3·75-5 μ, aliis hyalinis, filiformis, rectis vel flexuosis, pluriguttulatis, 20-60 ⩔ ·6-2 μ.

In culmis *Sacchari officinarum* in India, or

As this fungus is possibly the lower stage of a Pyrenomycete, attempts were made to obtain an ascigerous stage in culture on organic media. The following were tried :—Potato, carrot, onion, plantain, *Colocasia* corm, fruit of *Carica Papaya*, fruit of *Psidium Guajava*, boiled rice, bread paste and sugarcane pith. The last medium was the only one, besides nutrient agar, in which pycnidial stromata were developed and none gave rise to

* *c.f.* Harter, L. L. & Ethel C. Field. *Diaporthe*, the ascogenous form of sweet potato dry rot. Phytopathology, II, 1912, p. 121. Roberts, J. W. A new fungus on the apple. *ib.*, p. 263.

an ascigerous stage. After a week the onion cultures were the best, followed closely by carrot, potato, *Carica, Colocasia, Psidium* and rice. On bread also the growth was good, while plantain and sugarcane were much inferior, especially the last. The mycelium was loose and had begun to lose its original white colour in many of the tubes, the upper part of the aerial mycelium (which exceeded 2 inches in height in some of the cultures) turning grey, except in the plantain, rice and sugarcane tubes, while the growth near the surface of the medium remained white in all. A submerged growth had developed in the water in the bottom of the (potato) tubes and this became light purple or pinkish in the carrot, onion and *Carica* tubes. The medium was discoloured dirty grey in the onion tubes, eye-grey to purple in those of rice and slaty-blue in those of bread. Five days later a blackish crust had developed on the surface of the water in the potato, carrot, onion, *Carica* and *Psidium* tubes, the submerged mycelium was light cinnamon colour in the onion and *Psidium* tubes, brick red in the plantain, and unchanged in the others. The colour had diffused into the water. The aerial growth was turning brown on the surface in the carrot, onion, plantain, *Colocasia, Carica, Psidium* and bread tubes, with a little pink in places in those of *Colocasia*. The medium was blackened in the potato, carrot and *Carica* tubes, while the upper part of the rice was dark coloured and a bluish line separated this from the unaltered lower portion; the same bluish colour developed in the upper part of the bread paste. Seventeen days later there was little change, the growth in the potato and onion tubes was darker, that in the carrot, plantain, *Carica* and *Psidium* tubes had become pinkish in places, the submerged mycelium was chocolate-brown in the plantain, and chestnut in one of the sugarcane tubes, and a few dark dots were noticed in the denser parts of the mycelium of several tubes. These did not develop further and were ultimately found to be merely condensations of sterile mycelium.

The following inoculations were carried out with pure cultures, obtained as above described.

In October, 1909, 35 canes in a plot of strong healthy Red *Mauritius, about 7 months old*, were inoculated at Samalkota by *removing a cylinder, about half an inch in length, with a small*, flamed cork borer and inserting a small tuft of mycelium. The cylinder was replaced after cutting a little off the end, and the wounded stem bound with sterile gutta-percha sheeting. Seven weeks later, two of the inoculated canes commenced to wither. In January, 1910, another inoculated cane withered and was sent to Pusa for examination. The condition of the stem was similar to that in the canes from which the fungus was first obtained. The inoculated internode was bright red. The reddening extended upwards for 3 internodes, the 3rd having only one bright red bundle. Higher up, the translucent, watery condition of the pith, already described, was found. Downwards, the reddening extended for 2 internodes. Hyphæ were numerous in the reddened parts and pure cultures of the fungus used in inoculating were obtained readily. In February, four more of the withering inoculated canes were received, as well as two non-inoculated canes arising from the same clumps, which seemed to have become infected secondarily. The inoculated canes had typical symptoms. In two, the infection had extended downwards to the base of the stool, the upper part being less affected. In the other two, distinct reddening occurred for 2 or 3 internodes above the wound and the pith was translucent and hollow in the centre for some 10 internodes higher. The hyphæ were, as usual, confined to the reddened portion, where they were plentiful and easily obtained in pure culture, giving rise to the same fungus used in inoculating. The two non-inoculated canes had become infected from below ground, apparently through the roots, and were withering as a result of the attack. The fungus was recovered from these canes also. Early in March the plot was inspected by one of us (E. J. B.). A number of the inoculated canes had withered and the disease had extended in some cases to other canes in the same clumps. The rest of the plot was quite free from disease, except where the second series of inoculations, to be described below, was located. The symptoms were typical and left no doubt of the success of the inoculations.

On the same date as the last, a second series of inoculations was carried out in the same plot, by removing the soil from around the base of four clumps of cane and watering the exposed roots with a suspension of the mycelium beaten up in water. These also took well, and when seen early in March each clump had one or more withered canes. No other canes were withering in the rest of the row to which the clumps belonged nor, so far as could be observed, in any part of the plot, except the row in which the first series of inoculations had been made. One cane from each clump was split and found to have typical symptoms of the disease, but there was no opportunity for microscopic examination. The symptoms were, however, so definite that there was no doubt that this series was quite as successful as the first.

As the disease does not occur at Pusa, it was not considered advisable to carry out any inoculations in the field. Some were, however, made on plants growing in tubs, at a distance from the farm crop. The number of canes inoculated through stem wounds was six, growing in four tubs, one tub being kept as a control. The inoculations were made in November 1909, exactly in the same manner as those of the first series at Samalkota. In the following March none of the inoculated canes had withered and two were removed for examination. The inoculated internode was found diseased in both, the mycelium being confined to the one internode in one case but extending to the next higher up in the other. The other plants were kept in the tubs until the following year, by which time they were still alive but had ceased growth, except for a few feeble side shoots. In May 1911, they were cut and examined. The inoculated canes were much reddened near the wound, the reddening extending for from 2 to 4 internodes each way. Above the reddened part, the characteristic translucent appearance and internodal hollowing of the pith was found. The red parts were full of the hyphæ of the parasite and, in one case, pycnidial stromata had developed in the internode next below that inoculated. The roots were not affected and no spread to other shoots in the same stool had occurred. The parasitism was, therefore, much less marked than at Samalkota, though the spread of the

mycelium in the living tissues indicates a certain degree of parasitic activity.

In three other tubs, the main canes of which had been injured and in which a "ratoon" crop was growing, inoculations similar to those of the second series at Samalkota, were made in December 1909, the exposed roots being watered with a suspension of the fungus. No outward sign of disease appeared, and the following April the stools were uprooted, as also that in the control tub. All were found perfectly healthy and no trace of the parasite could be detected in the tissues.

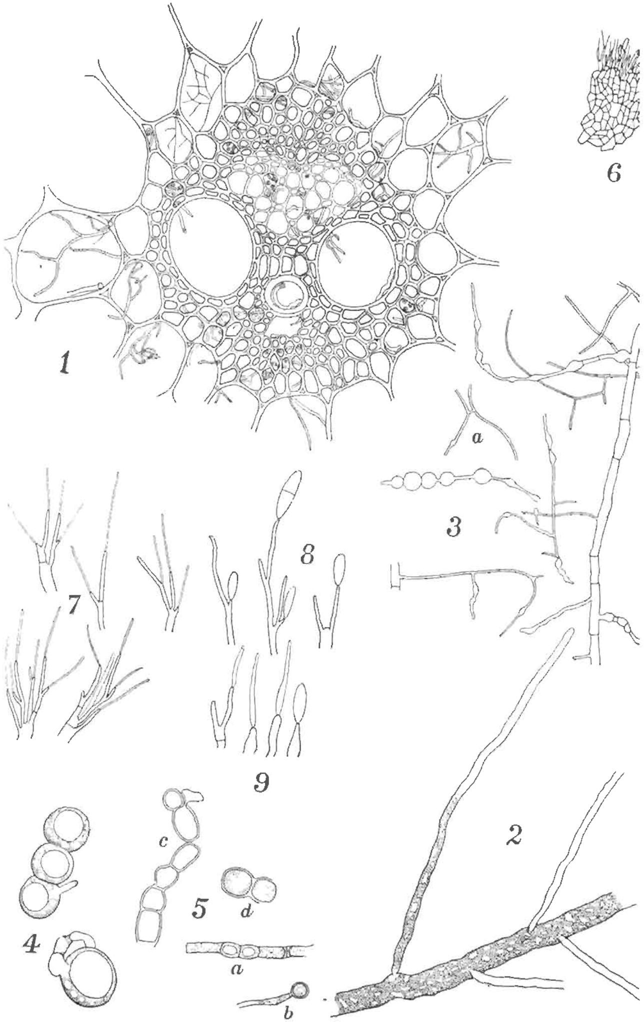
It seems probable, therefore, that the disease is restricted in its distribution by climatic or other unknown conditions, as so many of the fungus blights of crops in India are. How much damage is caused by it is unknown. Both at Samalkota and Jorhat it was enough to cause uneasiness, but in the latter case it is still uncertain whether there are not two diseases at work. If it should be found that the condition observed at Jorhat, in the Central Provinces, and elsewhere, of excessive tillering, combined with degeneration of the plant, sometimes to such an extent that no true canes at all are formed, the whole plant remaining grass-like, is caused by this parasite, then it will have to be reckoned as a serious disease. Meanwhile, further investigations are in progress and it is hoped that the publication of the present description will lead to the recognition of the disease, where it occurs, and fuller observations on its field characters. It is obviously impossible, at present, to suggest methods for its check beyond the ordinary precautions urged on previous occasions for routine observance in sugarcane cultivation in India.

Description of Plates III, IV and V.

(*Hendersonina Sacchari*, Butl.)

Plate III.

Fig. 1. Section of a sclerotium of *Hendersonina Sacchari*, probably formed by the union of several unilocular stromata. Each cavity is surrounded by a separate pseudo-parenchymatous wall, between which the structure is filamentous. A mass of spores of both types is extruding from the mouth of the left-hand cavity.



6
1
a
3
8
7
9
2
c
4
5
d
a
b

Hendersonina Sacchari

Fig. 2. Ripe sclerotium in longitudinal section, showing the irregular loculi, immersed in a pseudo-parenchymatous stroma. The cavities were filled with spores, which are not shown.

" 3. Another ripe sclerotium in transverse section. At the base, this sclerotium showed only two large loculi. Near the apex there were seven cavities, arranged roughly in a ring and mostly opening by a common mouth.

PLATE IV.

Fig 1. Transverse section of part of the pith of a cane, infected by *Hendersonina Sacchari.* The hyphæ grow from the intercellular spaces into the cell cavities. Intermediate and fine hyphæ are present, but not the very thick kind. X 190.

" 2. Very thick hypha from the surface growth obtained on incubating an inoculated cane. Branches of intermediate diameter are numerous. These in turn will give off very fine threads. Septation has not yet occurred. X 350.

" 3. Mycelium from a culture, showing fine and intermediate hyphæ and chlamydospores. The fine branches are irregularly swollen, and at *a*, two have anastomosed by a side branch. Later stage of growth than Fig. 2. X 350.

" 4. Chlamydospores separated from the mycelium and germinating. X 500.

" 5. Formation of chlamydospores. *a* early stage, intercalar; *b* ditto, terminal; c a chain separating from the mycelium (one is germinating). *d* old chlamydospores from a chain, that on the right has lost part of its exospore. X 350.

" 6. Part of the wall of a pycnidium, showing the abrupt transition from the sclerotial cell layers to the basidial layer.

" 7. Basidia with filamentous spores (scolecospores). X 625.

" 8. Basidia with the broad type of spore (pycnospore). X 625.

" 9. Simple types of basidium, the 3 on the left with hyaline scolecospores of a broader type than usual, that on the right with a young pycnospore. X 625.

PLATE V.

Fig. 1. Pycnospores of *Hendersonina Sacchari.* X 520.

" 2. Scolecospores of ditto. Some stromata contain only the narrow type, uniform in diameter shown at *a a*, others the more irregular forms. X 520.

" 3. Intermediate type of spore between the pycnospore and scolecospore types. X 520.

" 4. Germination of the pycnospores, early stages (24 hours after sowing). X 520.

" 5 Ditto, later stages (48 hours after sowing). X 520.

III.—Helminthosporiose

(*Helminthosporium Sacchari* Butl. n. sp.).

A species of this well-known genus, many members of which are parasitic on *Gramineæ*, is common on the leaves of sugarcane at Pusa. The infected leaves first show small red spots, which spread rapidly, chiefly in a longitudinal direction and especially towards the tip of the leaf, may run together to form long streaks. The centre of the spot soon changes to a dirty straw colour, around which the margin remains red for a time and then changes to dark brown. The spots occur equally on the midrib, where they may be confused with those caused by the leaf form of *Colletotrichum falcatum*,* and on the thinner part of the leaf. When numerous, they cause death of the leaf tissues beyond the limits of the spots: the tip of the leaf often withers completely and there may be long withered strips down the margins.

The mycelium of the parasite is found in the leaf cells of the spotted portion and also collects in small stromatic masses on the surface of the spot. The hyphæ are brown at the surface and in the outer cell layers, but hyaline deeper in. They pass from cell to cell through narrow cracks in the walls (Pl. VI, Fig. 2), which are especially noticeable in the thick-walled sclerenchyma which overlies the bundles, but within the cells are swollen so as almost to fill the cavity in the smaller cells. In the epidermis they frequently form small stromatic masses. The cells appear to be killed in advance of the growth of the fungus, as although the hyphæ are numerous in the dead cells, it is rare to find penetration of a still living cell.

As soon as the centre of the spot begins to turn straw-coloured, fructification occurs by the growth of sporophores from

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* Butler, E. J. & A. Hafiz Khan. Red Rot of Sugarcane. Mem. Dept. of Agric. in India, Bot Ser., VI. No. 5, 1913.

the stromata, both those within the epidermal cells and those on the surface of the leaf.

The sporophores are stout, erect, rather rigid hyphæ, which arise from the peripheral cells of the stromata (Pl. VI, Fig. 4). They are usually unbranched, 3 to 10 septate, dark greenish-brown below, paler above and several times bent or "geniculate." Spores are produced at each bend and at the apex, the lowest being the first formed and the bent condition being due to the spores being always apical at first and being then pushed to one side by continued growth of the sporophore from just below the insertion of the spore. The sporophores are 100 to 190 μ long, by 5·5 to 7·5 μ broad.

The spores (Pl. VI, Fig. 5) are borne singly and readily fall off. They are cylindrical or long elliptical in shape, with very thick walls, and divided into from 4 to 11 compartments by broad partitions. The colour varies from olive green to brown and the size from 35 to 60 μ long, by 8·5 to 12 μ broad.

Germination occurs rapidly (within 3 hours in some cases) by the protrusion of a germ-tube from each end of the spore. At the same time the internal partitions sometimes break down in the centre (Pl. VI, Fig. 6). Part of the mycelium formed from a single spore culture in a hanging drop, is shown in the text figure:

drawn 48 hours after sowing. The fungus can be readily cultivated on most ordinary media, but the spores formed in culture are usually smaller than those from the host plant. The following inoculations were made with pure cultures on nutrient agar.

In January 1909, 8 leaves of growing sugarcane were inoculated on the upper surface with a suspension of spores and mycelium, a drop of which was placed on each leaf and covered with damp, sterile cotton-wool. The leaf was not injured in any way. After 6 days, 3 of the inoculations were found to have succeeded, a red spot developing at the inoculated point and eventually giving rise to a typical infection. The other 5 and the controls showed no change. A second series was made at the same time on young healthy shoots brought into the laboratory. On these 6 inoculations were made, 3 being kept damp with cotton-wool and 3 by covering with bell-jars. The latter showed evident signs of infection in 2 days, but only 1 of the former succeeded and the spot was not visible until the fourth day. A month later 9 more inoculations were made on healthy shoots kept under bell-jars, all of which succeeded. One showed reddening in 24 hours, 4 more were visible in 3 days, and all were well marked in 5 days. A little later, 21 more inoculations were made in a similar manner to those of the last series. All succeeded well.

The microscopic examination of the inoculated leaves showed that penetration occurred directly into the epidermal cells (Pl. VI, Fig. 3). The infecting hypha swells up slightly in close contact with the cuticle and a narrow tube arises from the swollen portion and pierces the wall. As soon as the cell cavity is entered, the hypha swells up again and becomes freely septate, often forming a small mass of pseudo-parenchymatous cells. From this, branches pass to the deeper cells, and others approach the surface to form new stromata. The pressure exerted by these epidermal stromata is sometimes enough to rupture the outer wall before reproduction begins. The fructifications are usually confined to the quite dead central part of the spot.

The species does not seem to agree with any of those previously described. About 30 are known on various grasses, but none on *Saccharum*. The diagnosis is as follows :—

Helminthosporium Sacchari Butl. n. sp. Maculis amphigenis, elongatis, initio rubris, dein avellaneis vel stramineis ac ferrugineo-marginatis, 3-25 × 2-6 mm; cæspitulis minutis, atris; hyphis fertilibus erectis, simplicibus, 3-10—septatis, geniculatis, olivaceo-brunneis, apice pallidioribus, 100-190 × 5·5-7·5 μ; conidiis acrogenis, cylindraceis vel oblongo-ellipticis, utrinque rotundatis, 3-10-septatis, crassissime tunicatis, olivaceo-brunneis, 35-60 × 8·5-12 μ.

In foliis *Sacchari officinarum* in India, or

A fungus which, from the published descriptions, bears a considerable resemblance to the above, is known in Java and Hawaii under the name of *Cercospora Sacchari*, Br. de Haan. It was first described by Breda de Haan in Java,* as the cause of a leaf disease to which the name "eye spot" was given. A further account was subsequently published by Dickhoff and Hein†. In Hawaii it has been briefly described by Cobb‡. From the figures published in Wakker and Went's well-known text-book of sugarcane diseases§, it appears probable that this fungus is really a *Helminthosporium* and not a *Cercospora*. A comparison of the two fungi has not been possible and could alone settle the question of their identity.

Little requires to be said regarding the treatment as, so far, this disease has not been found to damage the crop materially. If it became severe, it would be advisable to strip off and destroy the affected leaves in the early stages of the attack (we have found the first spots in June, at Pusa). There are a good many

* Breda de Haan, J. Van. Rood Rot en andere Ziekten in het Suikerriet. Meded. van het Proefstation West Java, XVI, 1892.

† Dickhoff, W. G. & S. A. Arendsen Hein. Eenige Waarnemingen omtrent de Oogvlekkenziekte. Archief Java Suikerindustrie, IX, 1901, p. 865.

‡ Cobb, N. A. Fungus Maladies of the Sugarcane. Exper. Stat. of the Hawaiian Sugar Planters' Association, Division of Pathology and Physiology, Bull. No. 6, 1909, p. 36.

§ Wakker, J. H. & F. A. F. C. Went. De Ziekten van het Suikerriet op Java. Leiden. 1898, *Pl.* XXI, *figs.* 1—5.

leaf diseases of sugarcane, but they cause little loss as a rule and, even in more advanced countries than India, do not seem to require treatment.

PUSA,
August 5th, 1913.

DESCRIPTION OF PLATE VI.

(*Helminthosporium Sacchari* Butl.)

Fig. 1. Section through leaf of sugarcane, showing hyphæ of *Helminthosporium Sacchari* in the outer cells. X 350.

,, 2. Part of a similar section, to show passage of the hyphæ from cell to cell. X 500.

,, 3. Infection of upper surface of leaf, from an inoculation, showing penetration of the outer wall of the epidermis and formation of small stromatic masses in the epidermal cells. X 930.

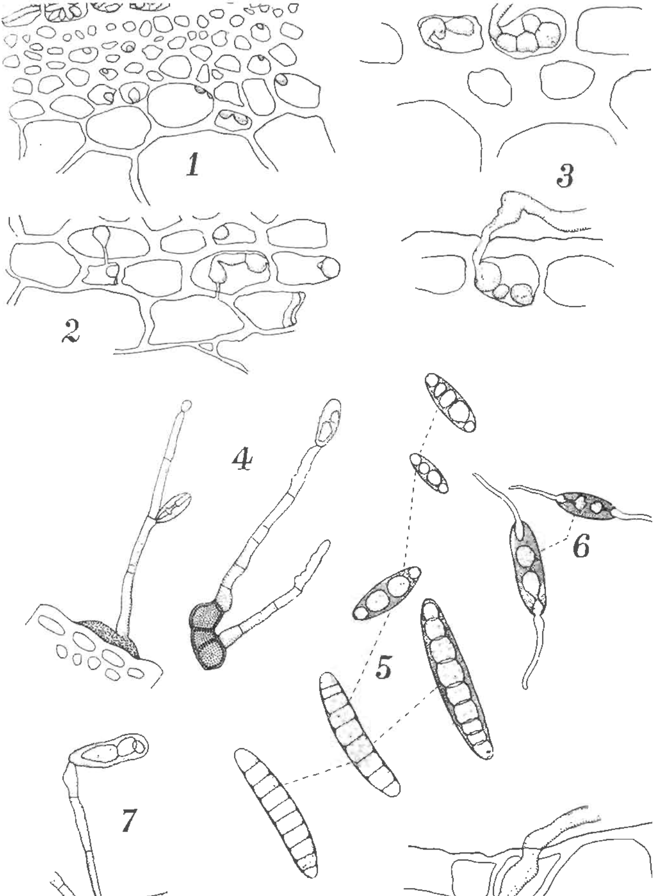
,, 4. Conidiophores with young conidia. X 350.

,, 5. Conidia. The three upper immature, the three lower mature. X 500

,, 6. Germination of the conidia. X 500.

,, 7. Reduced conidiophore and conidium, from a pure culture. X 350.

,, 8. Base of conidiophore, arising from within the epidermis and emerging across the cell wall, not through a stoma. X 500.



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PRELIMINARY NOTE ON THE CLASSIFICATION OF RICE IN THE CENTRAL PROVINCES

BY

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I.—Introductory.

Preliminary.—The work of classifying the rices of the Central Provinces has been in progress during the past five years. The present memoir is a summary of the work to date, and is published in the hope that the results attained may prove of service to workers in other parts. The materials on which the enquiry was started were the rices collected from all the districts in the Central Provinces for the Central Provinces and Berar Exhibition of 1908. In the succeeding years this collection has been added to, largely through the kindness of District Officers, till at the present time a collection of 670 rices has been received. In cataloguing the specimens the vernacular names by which the rice was known in its own district have been made use of, and it must be clearly understood, that the 670 rices referred to above represent only vernacular names and not necessarily distinct varieties. As a matter of fact, the vernacular name is no guide to the identification of a rice, *e.g.*, the same vernacular is often applied to totally distinct rices in different districts ; while, on the other hand, the same rice often bears different names in different districts ; for example, the outstanding purple rice is named *Nagkesar* in Chhattisgarh, *Jalkesar* in Jubbulpore and *Mahaprasad* in Nagpur.

Area.—In 1911-12, the most recent year for which figures are available, the area under rice in the Central Provinces was 4,780,560 acres out of a total of 17,961,358 under crop. In Berar 41,487

acres out of 7,057,414 were under rice. Thus in 1911-12 rice constituted 26·6 per cent. of the total area under crop in the Central Provinces or 19·2 per cent. of the whole area under crop in the Central Provinces and Berar.

The earliest complete figures available are for the year 1885-86, when rice occupied 3,170,360 acres out of 13,466,675 under crop, in the Central Provinces, which at that time included Sambalpur, while in Berar the area was 25,832 out of 6,558,379 acres under crop, with percentages of 23·5 per cent. and 15·9 per cent. for the Central Provinces and Berar respectively. Rice moreover occupies the largest area in the Central Provinces, its nearest rival being wheat which occupies 14·8 per cent. of the area. In the Central Provinces and Berar rice and cotton respectively occupy nearly the same area, cotton being slightly the greater and taking up 19·5 per cent. of the whole.

Detailed figures for 1885-86 and 1911-12 for each district are given below in a tabular form.

District.	Area in 1885-86.	Area in 1911-12.	
	Acres.	Acres.	
Saugor	12,575	17,816	
Damoh	49,163	49,358	
Jubbulpore	1,22,160	1,36,131	
Mandla	47,385	1,22,312	
Seoni	1,06,103	94,634	
Narsinghpur	25,659	44,144	
Hoshangabad	11,465	11,984	
Nimar	12,569	12,357	
Betul	12,096	12,059	
Chhindwara	5,415	11,578	
Wardha	4,050	4,349	
Nagpur	32,763	28,948	
Chanda	1,89,330	2,51,777	
Bhandara	2,72,855	4,85,153	
Balaghat	2,27,385	2,84,252	
Drug	..	6,55,099	
Raipur	11,44,757	14,28,568	
Bilaspur	7,16,620	11,19,023	
Sambalpur	1,76,013	..	Transferred to Bengal.
Amraoti	559	6,150	
Akola	331	16,171	
Ellichpur	4	..	Included in Amraoti.
Melghat	4,293	..	Ditto
Buldana	6,180	5,282	
Wun	2,956	..	Included in Yeotmal.
Yeotmal	..	13,884	
Basim	11,509	..	Included in Akola.

The principal rice growing tracts (*vide* Map) of the south of the Province are the portions of Bhandara, Balaghat and Chanda lying in the Wainganga river basin all in the Nagpur Division, and Drug, Raipur and Bilaspur in the Chhattisgarh Division. In the north of the Province the south-east portion of Seoni with Burghat as a centre, parts of Mandla and the southern portion of Damoh with the two adjoining Tahsils of Jubbulpore, constitute the most important areas.

Rice Soils.—The rice-producing soils of the Central Provinces are formed almost entirely upon Pre-Cambrian rocks of the Purana and Archæan groups. The formations generally represented are the Upper and Lower Vindhyan in Damoh, Bilaspur, Chanda, Drug and Raipur; the Chilpi Ghat series of the Dharwar formation, formerly known as the Transition or Sub-metamorphic, in Bhandara, Balaghat, Drug and Bilaspur, and the Metamorphic and Crystalline formation in parts of Jubbulpore, Chanda, Balaghat and Bhandara.

The actual material derived from the weathered rock is greatly modified in many cases by rain wash and admixture with soils of other types. The typical rice soils of the Central Provinces have a high proportion of coarse particles and a correspondingly low proportion of clay, being suitable only for single cropping. The heavier soils suitable for double cropping are much finer in texture and therefore more retentive of moisture.

Composition of typical rice soils of the Central Provinces:—

A. Locality, Adhartal, Jubbulpore, a gneissic detritus.
B. ,, Katangdhara, Chanda, a gneissic detritus.
C. ,, Labhandi, Raipur, a yellow *metasi* soil overlying Raipur limestone.
D. ,, Lanji, Balaghat, yellow *sehar* soil formed from Dharwar rocks.
E. ,, Tharsa Nagpur, a black *morund* soil overlying crystalline rocks; suitable for double cropping.

		A	B	C	D	E
Coarse sand 1–·2 m.m. diam.	..	22·59	43·38	5·66	12·69	16·45
Fine sand ·2–·04 m.m. diam.	..	37·57	20·15	19·08	28·51	11·53
Silt ·04–·01 m.m. diam.	..	17·77	7·88	38·82	24·79	13·66
Fine silt ·01–·002 m.m. diam.	..	7·93	10·63	19·22	14·31	15·76
Clay below ·002 m.m. diam.	..	11·10	13·05	11·67	13·00	34·79

	A	B	C	D	E
Calcium Carbonate	0·31	0·20	0·08	0·04	1·18
Loss on ignition	2·42	4·47	3·58	3·19	5·02
Nitrogen	·57	·27	·44	·45	·48

Cultivation.—Rice is grown throughout the Central Provinces as a rains crop, only in the Sironcha tahsil of Chanda is a cold weather rice crop grown. This is locally known as *jimsara* or *grishma kal.* Briefly stated there are three methods of rice cultivation. The first is broadcast sowing, general names for which are *bootia* in Bhandara and *bota* or *boar* in Balaghat. This takes place either before or immediately after the first showers of the monsoon. Dry broadcast sowing is known as *khurra* in Chhattisgarh and as *topa* or *jhura* in Damoh, while wet broadcast sowing is termed *rasbeetara* in Chhattisgarh and also *batar* in Bilaspur and Drug. In the latter district *hogdum* is the name applied to wet broadcast sowing when the seed is covered by the plough. *Antia* is the term used for wet broadcast sowing in Chanda and Bhandara. A variation of wet broadcast sowing is common in the Chhattisgarh Division, in Balaghat and Chanda and in Damoh and Jubbulpore districts. The rice grains are placed in an earthen pot or a basket and thoroughly moistened. This is then covered with cow-dung and straw. In 2–4 days the grains germinate. The artificially germinated grain is then broadcasted in fields which have been carefully puddled. This process is known as *lehi* in Chhattisgarh, *kaorak* or *lehi* in Drug and Balaghat, *mulka* or *kaorak* in Chanda and *kaorak* in Bhandara. In the Northern districts it is called *machhawa.*

The second method of rice cultivation is *biasi* which consists of broadcasting the rice by any of the methods mentioned above, followed by a second process of ploughing when the plants are a foot high. *Biasi* is confined almost entirely to the Chhattisgarh Division.

Thirdly, transplantation called *ropa* in Drug, *rohna* in Chanda, and *rohna* or *parha* in Balaghat and Chanda, a process by which the seed is sown in carefully prepared and heavily manured nursery beds at the beginning of the monsoon; when the plants are 12—18

inches high, they are planted out in the rice fields, which have been especially prepared. The advantages of this method, when properly carried out, are a considerable saving in seed, a marked increase in yield and an improved quality. The chief disadvantages attaching are the necessity of a large supply of labour at one time, the necessity of opportune rain, in the absence of irrigation, to enable the fields to be prepared and a decided lengthening of the time necessary for the crop to mature. The physiological factors involved in transplantation are somewhat obscure, but the conclusion at present, arrived at after a number of experiments, is to the effect that transplantation acts in a way like root pruning, the injury to the root system stimulating the growth of the sub-aerial portion and resulting in increased tillering. The root system of the transplanted rice is developed from the lower nodes of the stem, the first or seedling root system in many cases dying completely. In fact a series of experiments shewed that amputation of the root system of the seedlings did not interfere with the development of the transplanted plants.

In Basim taluk of Akola rice is sown in open fields in lines by means of a drill. In the Zamindaris of Chanda the *khanori* system of rice cultivation is practised. A piece of jungle is cleared in the hot weather. When the ground has been covered with wood to a depth of a few inches, the whole is set alight. Rice is then sown in the ashes and this ends the cultivation. This method which is also followed in other jungly parts of the Province is known elsewhere as *dahia*.

Broadcasting is the usual method of cultivation in the Central Provinces. Out of the total in 1911-12, 3,154,908 acres were under broadcast rice. The practice of transplantation which until a few years ago was unknown in Chhattisgarh is being introduced into the Division with great success. The area has risen by 25,000 acres within the last five years. Practically throughout the Province the crop is grown in embanked fields. These embankments collect the rain water. Only in hilly tracts in a mixture with *Kodo* and *Kutki* or as a catch crop in certain parts of Wardha, Jubbul-

pore, Betul and Hoshangabad are quickly ripening rices sown in open fields.

Methods of work.—The line of attack has been by means of pure cultures. Every rice received has been observed in cultures as follows:—From each variety sent in, four of the largest and at the same time most typical heads were selected. In a number of instances where the sample was very impure, subordinate types were selected; in some cases as many as six were found necessary as for instance in *Sikia Bikia* (Jubbulpore). Of these heads three were mounted as herbarium specimens for reference, while the grains from the fourth were removed and placed in an envelope preparatory to sowing. The contents of each envelope were sown in a line and the produce compared with the specimen on the herbarium sheet. Where the produce differed from the type, further pure cultures were made, heads being selected from the original sample, and at the same time the types found in the produce were separated out as indicated in the case of the original selection. In this way it was possible to check results, and at the same time to observe how far natural crossing took place. So far no cases of natural crossing have occurred in the line cultures. The occurrence of the grains of a wild rice, *Tari*, in many samples of rice received from Raipur together with the fact that the presence of *Tari* in a rice field is held by the cultivators to lead to the deterioration of the crop suggests however the occurrence of natural cross-pollination. This is particularly interesting on account of the occurrence of a similar phenomenon in Texas.(1) The presence of a small quantity of red rice plants is sufficient to vitiate a white rice crop which can only be kept pure by the weeding out of the red grains before sowing. Since this preliminary note was written, Hector(2) has shown that natural cross-pollination takes place at Dacca to an extent provisionally estimated at 4 per cent. The absence of any cross-pollination at Nagpur would seem to indicate that this only takes place under certain limited conditions. A further check was maintained by the selection of the produce of the best lines for trials on large plots. The produce of each of the original lines was compared and the best

were chosen for further trials against the best local varieties. This second selection served a double purpose. It raised the work of classification from the level of a mere piece of academic research to a work of practical value and it furnished a check, were such needed, on the observations made while the particular rice was grown in line culture.

Problems involved in Improvement.—There are two main openings for the improvement of the rice crop, depending on the quality and the quantity or yield of the rice. Generally speaking, the smaller and more slender grained rices are considered of a finer quality. A second quality found in combination with the finer grain is fragrance. This is a peculiar mouse-like smell possessed by the grain and also noticed when the rice is in flower in the field. This fragrance, though not appreciated by Europeans,—it is said that a distinguished member of the Agricultural Service soon after arriving in the country fell foul of his cook for serving him with rice with a mousey past—is held in high esteem by the natives of India.

These finer rices naturally weigh lighter than the coarse ones. The weight in 1911 of the grain from 200 heads of a coarse rice usually lay between 650 and 750 grams though *Gangawaloo* (Chanda) weighed 1,041 grams. On the other hand, a similar number of heads of a fine rice usually weighed between 300—400 grams, the lowest weight being 223 grams in *Bagmochh* (Jubbulpore). The first problem, then, is to get a high yielding fine rice. The second problem is simple, to improve the yield of the coarse rice.

A minor problem is introduced by the practice of polishing the rice before it goes to the market. In the polishing process the rice is liable to be broken and the price lowered. Generally the longer the grain the more liable it is to be broken. This is a second reason the first being the lighter weight of the grain, why the finer rices are usually nearly double the price of ordinary.

Wild Rice.—The investigation of the wild rices of the Province is still in progress. The following is a summary of the facts. Wild rice is common on the margins of tanks, *Dewdhan* (Jubbulpore), *Ghor*

Pashar and *Bal Pashar* (Raipur), in marshy places and as weeds in the rice fields '*Pashi*' and '*Sada*' (Jubbulpore), *Tari, Kala, Karanga* and *Karanga Pashar* (Raipur) and '*Parsad*,' of which there is an early and a late variety, from Chanda. The most important distinction between the wild rice and the cultivated is that the spikelets, when the grain is mature, are very deciduous. They are usually stoutly awned and have a dark red grain. The wild rices growing in tanks are usually tall, having the powers of adapting themselves to the depth of water in which they grow, and their grain takes longer to mature. The grain of the wild rices is harvested by Gonds and Dhimars who tie the rice plants into clumps and thus prevent the grain falling. The grain is sold to the poorer classes and is also used by devout Hindus on fast days (Upass) and on the 'Harchhat' festival.

The awned wild rices seem to agree with *Oryza sativa* var. *fatua*, Prain.(3) A wild rice from Raipur with a dirty white grain and an awnless wild rice from Bhandara appear to be cultivated rices and run wild. Watt (4) records the discovery by Duthie of *O. officinalis*, Wall, syn. *O. latifolia*, Desv., in Chanda. This wild rice differs from the others in having multiveined leaves. Its occurrence is reported from Allapilli and Sironcha. As already mentioned the occurence of '*Tari*,' whose grains do not fall down, mixed with many varieties from Raipur, suggests the occurrence of natural cross-pollination.

II.—CLASSIFICATION.

Preliminary.—The most recent publication on the classification of rice is the work of S. Kikkawa.(5) In this work two schemes of classification are given. The first divides the rices according to their agricultural characters, the second by the characters of the grain. Only the second is applied in classifying the Burmese rices. An older classification of rice, based solely on the grain characters, occurs in the "Handbuch des Getreides" by F. Koernicke.(6)

The use of agricultural characters in a *scheme* of classification demands a considerable amount of caution. In the rice plant we

may distinguish two characters which are developed owing to the special environment in which the plant grows. The first is the time of ripening and the second the water requirements of the plant. The first, however, is largely determined by the second. In a large area with markedly different climatic conditions in the North and South like the Central Provinces, where the crop is not entirely dependent on seasonal rainfall, and where many different systems of cultivation are in vogue, it is obvious that no hard and fast system of classification based on these agricultural characters can be laid down. This will be made clear by taking up the agricultural characters in detail.

Time of ripening.—The rices are broadly divided in these provinces into three main classes, *viz.*, early, medium and late. which correspond with the sub-divisions mentioned by Kikkawa.(7) Roxburgh. on the other hand. in classifying the Bengal rices recognises only early and late rices.(8) These terms refer to the time of harvesting of the rices. Early rices, many of which are ready for harvest by September, are sown on the higher fields where the water does not collect to a great extent, owing to the catchment area being small and their receiving comparatively little drainage. These are also the only rices sown as catch crops and in unembanked fields. The earlier the variety the poorer and more exposed the field it is sown in. Late rices are always sown on heavy soils, in embanked fields, and in low-lying places; as the name implies this is the last rice to be harvested, at times being on the ground until the middle of December, and unless the field is protected by irrigation, the success of this crop depends on the rainfall of September and October. Generally the late rices are grown in the fields that command the most assured and continuous supply of water. Medium rices are sown on land intermediate in character. They are longer in maturing than the early rices, but not so long as the late rices. Taking the average of the rices grown under observation an early rice matures in 121 days, the range being from 106 to 145 days; a medium in 125 days, the range being from 110 to 169 days; and a late rice in 133 days, the range being from 119 days onwards. The period be-

tween sowing and the appearance of the ears in the three classes is 87, 90 and 91 respectively. It is evident, therefore, that the earliness and lateness of a rice depends not so much upon the vegetative period of growth as upon the reproductive period during which the fruit matures and ripens. Though the rices fall broadly into these three classes, there appears to be a considerable latitude, even in one district, in placing any given rice in its class. The difference is still greater, when rices of the same class from different districts are considered. Thus early rices from Jubbulpore matured on the average in 113 days, the range being from 109 to 132 days: medium rices in 120 days, the range being from 117 to 129 days, and late rices in 128 days, the range being from 119 to 155 days. The early rices from Raipur matured on the average in 124 days, the range being from 105 to 145 days; the medium rices in 127 days, the range being from 112 to 141 days; and the late rices in 138 days, the range being from 123 to 155 days. Comparing these figures :—

Class.	Jubbulpore.	Raipur.
Early	113	124
Medium	120	127
Late	128	138

We find that the Jubbulpore rices are distinctly earlier in maturing than rices of the same class from Raipur. This is probably due(1) to irrigation in Raipur being far ahead of Jubbulpore, (2) to the practice of biasi in Raipur which delays the maturing of the plant.

This difference is due to irrigation and methods of cultivation in these districts, coupled with the wide range for the same class even from one district, shew how unsatisfactory a classification must be, based on the time of ripening of the rices.

Cold weather Rice:—Geemsal, a rice from the Sironcha tahsil of Chanda, is generally sown in January and harvested in March. This is an interesting variety as it is the only cold weather rice reported in the Central Provinces. The yield is said to be poor in spite

of heavy manuring and irrigation. Its survival is probably due to the isolated position of Sironcha and it will probably disappear as soon as the country is opened up. The rice can be grown in the rains, when it behaves like an early rice, and hence it may be placed with these.

Resistance to drought and flooding.—Rices fall into three main groups in regard to their water requirements, *viz.*, drought resistant, normal and flood resistant rices. The most highly drought resisting rices can exist for from 20 days to one month without water. In the North of the Province these are found amongst the early rices, elsewhere amongst the late rices. Flood resistant rices are found mainly amongst late rices. The longest period that a rice can withstand flooding is for about 15 days. If a suggestion may be made in explanation of the curious phenomenon that amongst the late rices both drought resistant and flood resistant varieties occur, may it not be that the danger of flooding to which the late rices, growing in the lowest fields, are exposed in their early stages, and the late date of maturing, occurring long after the seasonal rainfall has ceased, have evolved a type which may be both flood and drought resistant.

Height.—The average height of a rice plant is between two and half and three and a half feet. There are, however, amongst the early rices a large number which attain a height of only 18 inches to two feet. These may be classed as short rices. Only one example, *Pongha*, of the tall rices mentioned by Watt(9) has been found in the Central Provinces. It occurs in tanks in Chhattisgarh, Balaghat and Nagpur. The height varies with the depth of water, but specimens over 6 feet long are not uncommon. It is not proposed to make use of the height of the plant as a main point for classification. The tall rice is interesting as a systematic variety. It along with the short rices, falls into a group of systematic varieties which may be termed 'special rices.' As pointed out by Kikkawa(10) the shorter rices are less liable to lodge, but any advantage gained from this is more than counterbalanced by the fact that, so far as the Central Provinces are concerned, the short habit is associated with poor tillering and a small panicle.

Leaf.—The first diagnostic character noticeable in the young rice plant is the colour of the first leaf sheath. This can be observed five days after sowing. The normal colour is yellowish green, or a green usually distinctly lighter than the colour of the leaf. In certain classes, however, the colour is a shade of red or purple, in the latter case sometimes almost bordering on black. The colour may extend throughout the length of the leaf sheath, or may be confined to the lower portion, just above the ground level. The colour may further be either temporary or permanent. Generally speaking, the deeper shades are lasting, while the lighter shades may or may not disappear later. One interesting correlation has been observed in connection with the coloured leaf sheath. All rices which have a coloured leaf sheath have a dark coloured apiculus to the glume and palea. The converse is possibly also true, but there are still a few exceptions which are probably due to a very fleeting colour in the leaf sheath.

Coloured Rice.—In one variety of rice the plant is a bronze purple red and a field planted with this variety forms a striking contrast to its verdant neighbours. This is due to a coloured sap in the cells of the epidermis. In the young leaves the colour is developed mainly in the epidermal cells lying in the furrows between the sclerenchyma ridges. As was pointed out by Mookerjee(11) this variety would be a convenient one to select for introduction on account of the ease with which a field could be rogued. I agree with Kikkawa(12) in his decision that from an agricultural point of view the difference in colour should not be made a main point in a scheme of classification. From a systematic stand-point the colour of rice might well be described as a variety.

Ligule.—In the developed leaf another diagnostic character is found. The ligule which in the rice is continued round the sheath of the leaf as two ears or " sickles "(13) is either a light yellow colour or may be black with red. In the latter case the stem appears to have coloured bands or garters round it. These coloured sickles are commonly associated with a coloured leaf sheath, but the association is by no means invariable, as more than one rice with a

green leaf sheath have been found to have coloured sickles, *e.g.*, *Parewa* (Raipur).

Peduncle.—The peduncle in the rice is variable in length and may either be exserted from the last leaf (flag) or enclosed by it. In classifying rices, a peduncle is said to be 'enclosed' when the lowest branch of the inflorescence is within the leaf sheath, and 'exserted' when the lowest branch, easily recognised by its complete ridge of ciliate hairs, encircling the stem below the branch, is free from, that is visible above, the leaf sheath. The length to which the peduncle is exserted varies. Those with a peduncle more than half the length of the inflorescence have been described as 'far exserted,' those with a short peduncle simply as 'exserted.'

Inflorescence.—The panicle consists of a main rachis bearing primary and secondary branches. The rachis may be in one of three positions. It may be erect, curved or drooping. The last term is applied to a rachis which bends in a sharp curve.

Branches.—The branches of the inflorescence are all of the first and second order. The primary branches may either be approximate or separate. Further the primary branches, like the rachis, may be either erect, curved or drooping. In certain rices, branches of both kinds occur. In this case the lower branches are erect and the higher branches drooping. Taking the three types of rachis and the three types of branching, the following combinations occur. The rachis may be erect with approximate, that is, erect, branches—when the inflorescence is described as "erect." Secondly, the rachis may be curved more or less in a semi-circle with approximate branches—when the term "curved" is used, or the branches may be separated and themselves curved or drooping when the inflorescence has a feathery appearance. Lastly, the rachis may be "drooping" with approximate branches, when the inflorescence is drooping, or with separate branches when the inflorescence has again a feathery appearance.

Gammie (14) makes use of the average number of primary branches in order to distinguish the rices of the Bombay Presidency. It is not possible to use this as a diagnostic character in the Central

Provinces rices as the number of primary branches is extremely variable. Thus in '*Meghai*' (Raipur) the average number of branches was 10 with a range from 6 to 14 in 83 specimens examined; '*Jiro*' (Narsinghpur) had an average of 16 with a range from 13 to 21 in 61 specimens examined; '*Jhamul Meli*' (Raipur) had an average number of 11 with a range from 8 to 15 in 105 specimens examined. These three examples, taken from 64 medium rices examined, show how unsatisfactory this character is as a basis for classification. A range of eight is by no means uncommon, the ordinary range being six, and a range of less than five the exception. Two further examples will show that in certain cases the average number of primary branches does not even represent the number of greatest frequency

Rice.	No. of branches.	No. of specimens.
Laxmibhog	11	2
Raipur	12	10
	13	15
	14	17
	15	22
	16	14
	17	13
	18	10
	19	1
Average number 14; number of greatest frequency 15.		
Ari Motan	7	4
Raipur	8	14
	9	10
	10	7
	11	14
	12	4
Average number 9; number of greatest frequency indefinite.		

Spikelet.—The spikelets are articulated on their pedicels whic may be long or short. The pedicel is enlarged annularly at the to the two sides being distinctly oblique, that is, one side is high than the other. Just below the enlargement the pedicel is bent contorted. In many rices the facet(15) or annular enlargeme is expanded so as to appear scale-like. Hence Cook(16) in descri ing *O. coarctata* gives the number of glumes as 5, the spikelet bei jointed above the lowest pair. The size of the facets is of a certa amount of value in distinguishing the varieties.

Three main types of facets may be distinguished, *viz.*, ordinary (Plate III, Fig. 1), membranous (Plate III, Fig. 2), and ciliate (Plate III, Fig 3). In the ordinary type the facets are cup-like, the rim sometimes being thickened : in the membranous type the margin of the facets is flanged or might be described as having an expanded lip which is a membranous expansion. The ciliated facets have short erect hairs on the margins of the facets.

Each spikelet has three glumes, and a glume-like palea. The outer glumes are usually small and sub-equal, not exceeding $\frac{1}{3}$—$\frac{1}{4}$ of the inner glume. The inner glume and palea are sub-equal.

Clustered spikelets (17).—Although the spikelets are usually solitary, in '*Bahia Baikoni*' (Raipur) and '*Benie*' or '*Jhingofri*' (Jubbulpore) the spikelets are clustered on the secondary branches, from 2-7 occurring close together (Plate IV). The branches of the panicle have consequently a slightly interrupted appearance. The double grained rice indicates a direction in which we may look for an increase of the yield.

Outer Glumes.—The outer glumes are usually small, coriaceous and shiny. Glume I is inserted at a distinctly lower level than glume II. Both glumes bear the impress of the facets of the pedicel. The colour is usually somewhat paler than that of the inner glume and palea, ranging from a pale yellow approaching white through red to black. Ordinarily the outer glumes are inconspicuous, but in '*Bohila*' (Drug) and in '*Kalidhan*' (Hoshangabad) they are pale, while the inner glumes and palea are black. Further in '*Bhojraj*,' '*Naku*' (Hoshangabad) and '*Ranikajar*' (Jubbulpore) the outer glumes are dark, while the inner glume and palea are light. The colours of the outer glumes are useful in differentiating the varieties.

Rachilla.—Between the outer glumes and the inner glume the rachilla is frequently expanded in an annular thickening. This thickening tends to force the outer glume and palea apart. The extent to which the thickening is developed can be used to distinguish the rices.

Broadly speaking, there are two types of rachilla, *viz.*, comma-shaped and elbow-shaped (Plate II).—The comma-shaped rachilla has an enlarged thickened portion immediately under glume III, and the palea with a more slender curved stalk (Plate II, Figs. 1, 4). The elbow-shaped rachilla is uniformly thickened and does not show the distinction into head and stalk (Plate II, Figs. 2, 3).

Winged Spikelets(18).—The outer glume in '*Lal Pankha*' (Chanda), '*Pankha*' (Chanda), and '*Pakharya*' (Chanda) are large, equalling or exceeding the spikelets. Such rices have a characteristic winged appearance. This phenomenon, though interesting from a systematic standpoint, is limited to only a few rices and is not of much importance in the present scheme of classification.

Inner Glume and Palea.—The inner glume and palea are boat-shaped, nearly equal, longer than the grain and enclose it completely. Glume III is strongly 5-nerved, spinescently hairy on the nerves. The palea is narrower than the glume, 3-nerved, the nerves being spinescently hairy. The commonest colour is a pale yellowish white, but all colours from this to black, through red, occur. The colours are constant within limits, and are useful as diagnostic characters. Frequently the colours are confined to the furrows between the nerves, the nerves being themselves pale, while in a few rices the upper position of the glume and palea are one colour—commonly red, while the lower portion is another, usually pale yellow, the spikelet thus having a piebald appearance.

Apiculus.—The portions of glume III and palea are solid and project in a larger or smaller terminal point or apiculus. The apiculus and tip of the glume may be uniformly coloured with the rest of the spikelet or may be differently coloured, usually dark brown. At the time of flowering the tip of the glume is either concolourous with the rest of the glume, red or black. These two latter give the dark brown apiculus and tip of the ripe spikelet. As already pointed out, this colour is normally associated with a coloured leaf sheath. On either side of the apiculus are two smaller projections which make the tip

of glume III tridentate (Plate II, Fig. 2). These are described by Watt(19) as glandular processes. As stated later by Watt, they are simply excrescences of the lateral veins of the glume.

Awn.—An awn, if present, is borne on glume II. The awn may or may not be articulated on the glume. The length varies in different varieties from $\frac{1}{8}$ inch to $3\frac{1}{2}$ inches. Even within the same variety the length of the awn is by no means constant. The colour may be white, red or black, the first being the most common. The awn is scabrid and in the wild rice was undoubtedly associated with fruit dispersal and fixing the grain in the soil. In the Central Provinces no aversion is met with to awned rices; in fact, the best and highest quality rice *Chinoor* has an awn. In Damoh and Jubbulpore awned rices are sought after as the awns protect the crop from the attack of pigs.

Size.—The spikelets may be roughly divided into four groups Long spikelets in which the length is more than four times the breadth; fine in which the length is more than three times the breadth; coarse in which the length is more than twice the breadth; round in which the length is less than twice the breadth. Any attempt to give definite measurements of Central Provinces rices has ended in failure. True, an average measurement can be made out, but the labour and time required for this is in no way compensated by the results. For practical purposes the above is sufficient.

Shape.—Kikkawa(20) groups the rices into six classes according to the shape of the grain. No description is given of the classes and an unlettered photograph does not help to elucidate them Broadly speaking, there are five distinctive shapes found in the Central Provinces. The shape naturally depends on the curvature of the glume and the palea. The classes are as follows:—

I. Glume and Palea slightly convex. (Plate I, Fig. 1.)

II. Glume and palea convex. (Plate I, Fig. 2.)

III. Glume and palea very convex. (Plate I, Fig. 3.)

IV. Glume slightly convex, palea convex. (Plate I, Fig. 4.)

V. Glume slightly convex or straight, palea straight or slightly concave. (Plate I, Fig. 5.)

Among these five classes the first is by far the commonest. In the fifth class the shape often appears twisted or ≋ shaped.

As a rough guide to the meanings of these terms a slightly convex glume is four times as long as broad, convex three times, very convex less than three times: a slightly convex palea is five times as long as broad, convex four times, very convex less than four times.

Stigma.—Kikkawa(21) mentions that the colour of the stigma can be used to distinguish the rice varieties. Three colours are found in the stigma, *viz.*, white, red and black. The white stigma is found in the rices which have a green leaf sheath, the red in association with the red leaf sheath and the black with the purple leaf sheath. It is therefore of little use to bring in an additional character which is associated in the Central Provinces rices with another which can be more easily made out.

GRAIN.

Glutinous Rices.—So far as the present collection has gone, no examples of glutinous rices have been found in the Central Provinces. Glutinous rices have been experimentally grown on the Raipur Farm, but with little success. They were also imported during the shortage of the rice crop in 1907, but were not appreciated even in a year of scarcity, so there seems little likelihood of an opening for them in the Central Provinces.

An analysis of a number of Central Provinces rices by Hooper shows that the rices are in no way inferior to those grown in other provinces.

Colour.—According to the colour of the grain, the rices of the Central Provinces fall into two groups. The first group contains all the white rices, while the second contains the coloured rices. By far the commonest in the Central Provinces are the white rices.

The colour varies from pale yellowish white to a deep yellow. Amongst the coloured rices a dark terra-cotta is the commonest, but this may shade off into a light red or orange. The colour is contained in the pericarp. The process of polishing rice consists in the removal of the pericarp. This is rendered difficult by ridges on the grain. So far as can be ascertained, no objection is found to coloured rices, though, it is admitted that they are more difficult to polish and consequently are more liable to break in the process. There is no relation between the colour of the spikelet and that of the grain. In '*Naku*' (Hoshangabad) the spikelet is coloured, but the grain is terra cotta, while in '*Bainssa*' (Raipur) the spikelet is almost black with a pale yellow grain.

Size.—The size of the grain corresponds approximately with the size of the spikelet and the grains may accordingly be allowed to fall into the same classes in which the spikelets were placed with the exception of those with the long spikelet. No grain with a length greater than four times the breadth has been found in the Central Provinces. The length of the grain of a long spikelet and of a fine spikelet are greater than three times the breadth, of a coarse spikelet greater than twice the breadth and of a round spikelet less than twice the breadth.

Here it may be mentioned that while rices are naturally bought and sold on the character of the grain, a general preference is shown for rices which have a narrow grain, but opinion differs with regard to the length. In Jubbulpore a short narrow rice is esteemed, while in Raipur and Chanda a fine, that is, a long narrow grain is sought after.

Shape.—In shape, also, the grain usually follows the spikelet, though this is by no means invariable. Class I has a grain in which both sides are slightly convex and the shape is ellipsoid. Class II has a grain in which both sides are convex and the shape is broadly oval. Class III has a grain which is nearly round. In class IV the side of the grain next the glume is only slightly convex, while that next the palea is convex. In class V the two sides are nearly

symmetrical, both sides being parallel, or if the palea is concave, the grain is almost crescentic.

As already mentioned, the grain has ridges upon it which correspond with the nerves of the glume and palea.

Double Grains.—In a rice from Bilaspur and another from Narsinghpur the glume and palea are reported to enclose two or more grains. This variety has already been referred to by Prain(22) under the name of *Oryza sativa* var *Plena*. Like the coloured rice and the rices with clustered spikelets this also ranks as a systematic variety. In the present classification the distinction between single and double grained rices cannot be made a main distinction.

Abdominal White.—This term is used by Kikkawa(23) to describe the presence of a chalky white portion on the ventral side of certain rice grains. When it occurs in the centre of the grain surrounded by a translucent portion, the term 'Shiratama' is used to distinguish the grain. Inagaki, quoted by Kikkawa, believes that the abdominal white is nothing but a portion of the rice grain in which the spaces between the starch grains have not been filled up with albuminous substances. Most immature rices show an abdominal white and it appears on germination in grains which previously showed none.

Micro-chemical examination of the abdominal white shows that the starch grains are less closely packed in the cells in the chalky white portion and that the cells contain a large amount of dextrin. It would therefore seem that the abdominal white is an indication that a grain is immature and that the carbohydrate has not been converted into its most concentrated form. The appearance of abdominal white in germinating grains is then due to the conversion of starch into dextrin. It is obvious therefore that the use of the presence or absence of closely related carbohydrates in a portion of the endosperm as a basis for classification has nothing to recommend it.

Notched Grain.—Gammie(24) mentions the presence of a notch on the side of the grain as a diagnostic character in the rice varieties.

This character is difficult to make out and presumably refers to the depression left by the base of the style. In the rices of the Central Provinces this notch is found to be present or absent in the grains of the same head. It may be that the true notch has been overlooked in the present examination of the Central Provinces rices, but at present it is not possible to use this as a diagnostic character.

Embryo.

The embryo occupies an oblique position on the side of the grain covered by the glume. The embryo is normally the same colour as the grain, but the portion occupied by it differs from the rest of the grain in not being translucent. In certain cases the embryo, instead of being of the same colour as the grain, is distinctly dark, in the white rices a dark yellow and in red rices orange.

Outline Classification.—The distinctions brought out in this paper enable a comparatively simple classification to be made.

All rices fall into one of two groups, *viz.*, rices with a green leaf sheath and those with a coloured leaf sheath. The second class may be sub-divided into those with a red leaf sheath and those with a purple leaf sheath.

These classes further sub-divide on their vegetative characters, those of the spikelet and those of the grain. In addition to these morphological characters, the time of ripening, though not definite enough to form a main point in the classification of rices from a large area, is of considerable local importance. As already mentioned, the special rices are fitted into the general scheme of classification. They are so distinct that they may well be considered systematic varieties.

DESCRIPTION OF PLATES.

PLATE I.

Principal shapes of the spikelet in *Oryza sativa*, Linn. x C7.

Fig. 1.	Chitar Chuni (Raipur)	..	Type 1. Palea slightly convex, glume slightly convex.
,, 2.	Mendha (Chanda) ..	..	Type 2. Palea convex, glume convex.
,, 3.	Donkhi (Raipur) ..	..	Type 3. Palea very convex, glume very convex.
,, 4.	Selo (Raipur) ..	..	Type 4. Palea slightly convex, glume convex.
,, 5.	Dhamni Dhawool (Chanda)	..	Type 5. Palea straight, glume slightly convex.

PLATE II.

Principal shapes of rachilla in *Oryza sativa*. Linn, x C7.

,, 1.	Bainssa (Raipur) ..	..	Comma.
,, 2.	Dhana (Jubbulpore) ..		Elbow. Outer glumes red, glume III and palea common.
,, 3.	Chini Sakhar (Jubbulpore)	..	Elbow. The projection of the lateral nerves of glume III is distinct.
,, 4.	Deor Sagar (Raipur)	..	Flat comma.

PLATE III.

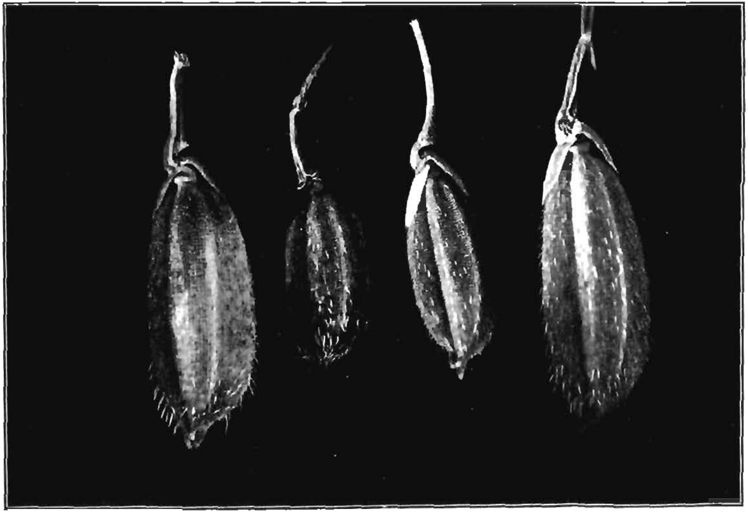
Types of facets in *Oryza sativa*, Linn, x C10.

,, 1.	Deor Sagar (Raipur)	..	Ordinary.
,, 2.	Dhana (Jubbulpore) ..	..	Membranous.
,, 3.	Dudhia sela (Chanda)	..	Ciliate.

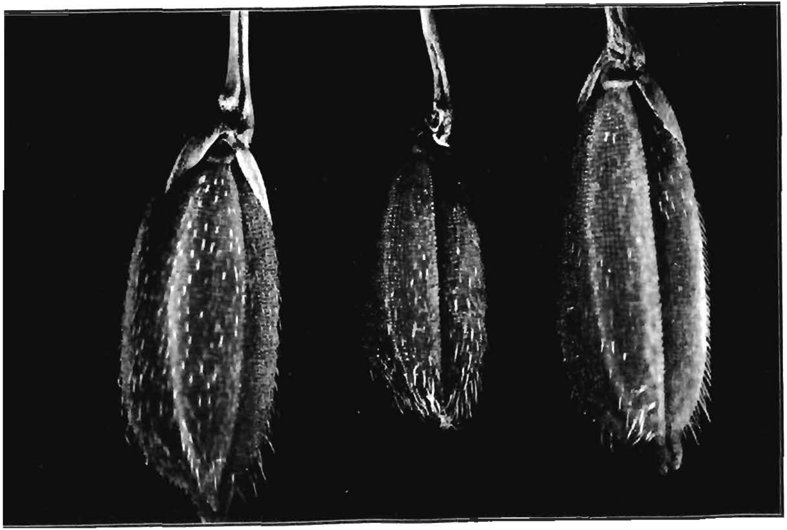
Plate IV.

Clustered spikelets in Bahia Baikoni (Raipur).

1. 2. 3. 4. 5.



1. 2. 3. 4



1. 2. 3.

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THE INFLUENCE OF THE ENVIRONMENT ON THE MILLING AND BAKING QUALITIES OF WHEAT IN INDIA.

No. 3. THE EXPERIMENTS OF 1911–12.

BY

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I. Introduction.

In the improvement of the wheat crop in India, the question of the influence of the environment on the quality of the grain is a matter of great importance. It affects not only the breeding of improved wheats but also the question of seed distribution. It has long been a vexed question as to what extent quality is determined by environment and how far it must be considered as characteristic of the race. To the plant-breeder, who wishes to combine in one strain the largest number of valuable qualities, a knowledge of the respective parts played by breed and by environment in producing and maintaining such qualities becomes essential. In the general aspect of seed distribution in India, it is necessary to know in what tracts wheats with high milling and baking qualities are possible. For instance, at the present time, the black cotton soils of the Peninsula and the canal irrigated tracts of Northern India produce for the most part soft, weak wheats often with poor milling qualities. One of the objects of this investigation is to determine whether or not wheats of better quality can be grown in these important areas.

The characters of the wheat grain which may be affected by change of environment are the following :—

1. *Colour.* While the general colour, red or white, of any wheat remains the same no matter under what conditions it is grown, nevertheless the depth or tone of colour in red or white wheats is not constant. In India, white wheats, when well grown under dry farming conditions, are frequently much darker in tint than the same wheat grown carelessly under a superabundant supply of canal irrigation. Similar differences are to be seen in red wheat.

2. *Size and weight of grain.* The size and absolute weight of the grain vary very considerably both in different localities in the same year and also in the same locality in different seasons.

3. *Composition.* Much of the work on the effect of environment on the characters of the wheat grain has been concerned with the effect of change of environment on the nitrogen content of the grain—the nitrogen content being taken not only as a measure of the percentage of gluten, but also as a rough indication of the strength of a wheat. There are, however, exceptions to the general rule that the higher the nitrogen the greater the strength so that, in the present state of knowledge, the only safe method of estimating strength is by milling and baking tests. Quality as well as quantity of gluten is important in this respect. For a flour to be really strong there must be sufficient gluten of the right quality present. So far, while no accurate relation has hitherto been found between chemical composition and the bread-making value of wheat, nevertheless the trend of recent investigations on this subject affords hope that the strength of wheat may be explained from a chemical standpoint. Thus Wood[1] has found in the case of Fife and other strong wheats that the water soluble phosphates in these flours is high—over 0·1 per cent. and the chlorides and sulphates very low. They also contain more magnesia than lime. Weak wheats, on the other hand, yield flours with a low proportion of soluble phosphates

[1] See Jago—*The Technology of Bread-making*, London, 1911, p. 323.

a high percentage of chlorides and sulphates with more lime than magnesia. Harvey and Wood[1] have published a preliminary note on a method of determining the baking strength of single ears of wheat by taking advantage of the differences in opalescence which exist between water extracts of various wheats.

4. *Consistency*. The effect of environment on the consistency of the wheat grain, *i.e.*, its translucent or starchy appearance, has been perhaps more thoroughly investigated than any other aspect of the question. There is no doubt that consistency depends very largely on the soil, on the available moisture and on the nutrition of the crop, and that, in many cases, great changes take place in this character in any variety according to the climatic conditions under which it is grown. From the miller's point of view, the consistency of the sample is of the highest importance and is one of the factors in determining the value of wheat. Consistency is commercially important in two ways. Firstly, it affects the process of conditioning or the adjustment of water previous to grinding —as a rule translucent wheats take up more water than soft samples. Secondly, translucent grains usually behave better than soft wheats in the mill and are more free grinding, thus enabling separation of bran from flour to be made with ease. As strong wheats are frequently translucent, translucency is sometimes considered to be an indication of strength, but this is not always the case as both translucent weak wheats and mellow strong wheats occur. In spite of these exceptions, however, the consistency of the grain remains a very important factor in the commercial valuation of a wheat.

Quality. Good quality in wheat flour has been defined by Humphries[2] as " the sum of excellence on several points " and these are five in number : (1) flavour ; (2) colour of the flour ; (3) strength, *i.e.*, size and shape of loaf ; (4) stability of dough ; (5) yield of

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[1] Harvey & Wood, *A Method of determining the Baking strength of single ears of Wheat*, British Association Reports, 1911, p. 597.

[2] Humphries, *Quality in Wheaten Flour*—a paper read before the Joint Session of the Chemistry, Botany, and Agriculture Sections of the British Association at Winnipeg, 1909.

bread per sack of flour. It is obvious that information on such points cannot be determined in any other way than by milling and baking tests. In seeking information on the effect of environment on the quality of the grain it is therefore essential to submit the sample to a complete test in the mill and bakehouse.

The experimental investigation of this subject in India was commenced in 1907 and the results obtained up to the harvest of 1911 have already been published.[1] In the present paper an account is given of the progress made during the wheat growing season of 1911-12.

The results published in the last paper were summed up as follows :—

"Usually in India the consistency of a wheat varies greatly according to the conditions under which it is grown. Some translucent wheats however are affected to a much less extent than others while a few soft wheats have always remained soft.

"Weak wheats like Muzaffarnagar can be improved to some extent in milling and baking qualities by cultivation but they have not been made to behave like strong wheats.

"Strong wheats with good milling qualities have been found to retain strength and milling qualities both under canal irrigation on the alluvium and also on the black soils of Peninsular India. In the future improvement of the wheats of these tracts, the question of grain quality should receive particular attention.

"Adverse factors, such as waterlogging and late cultivation affect both the yield and quality of wheat in the plains of India. In any particular wheat, the conditions which produce the highest yield are those which also produce the best sample. In the same wheat, high yield and high quality can be combined. To obtain the greatest financial return for his labour the cultivator should grow

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[1] Howard, Leake & Howard. *Memoirs of the Dept. of Agr. in India (Bot. Series)*, Vol. III, No. 4, 1910, p. 191, and Vol. V, No. 2, 1913, p. 49.

to perfection a wheat which combines high yielding power with high quality."

The earlier investigations carried out in Europe and North America, which bear on this subject, have been restricted to a great extent to the influence of external conditions on the composition of wheat. This literature is referred to in the previous paper. Since it was published one contribution to the subject has appeared which is dealt with below.

In the United States, Le Clerc[1] has continued his investigations on the influence of the environment on the composition of wheat. The object of these experiments was to determine the part played by soil on the one hand, and by climatic conditions on the other hand, in bringing about the well known differences in the appearance and composition of wheat caused by changes in the environment. For this purpose, samples of soil were interchanged among three localities—Maryland, Kansas, and California, which differ widely in climatic conditions. From each locality, sections of a normally fertile wheat-producing soil, five feet square and three feet deep, were dug up in three-inch layers, sacked and replaced in the same original position. The various samples of wheat grown were analysed and the results are set out in tabular form. They indicate that climatic conditions, far more than the soil, influence the composition and appearance of the wheat grain. As in previous years, milling and baking tests have not been included in the scheme and the conclusions are drawn from the analytical data only. It is unfortunate that the various samples were not milled and made into bread as these experiments would then have been most useful in throwing light on the influence of climatic conditions on milling and baking qualities. In order to obtain accurate information on the effect of environment on the behaviour of the same sample in the mill and subsequently in the bakehouse it is, in the present state of knowledge, unsafe to rely on chemical data only and on the appearance of the samples. Such important matters as strength of flour and the free-milling nature

[1] Le Clerc and Yoder, *Jour. of Agr. Research*, Vol. 1, 1914, p. 276.

of the wheats might easily be masked by changes in consistency and nitrogen content.

The agricultural conditions under which wheat is grown in India have been referred to in detail in the previous papers. There are two great wheat tracts in India which differ widely from each other, both as regards soil and as regards the source of moisture. The more important of these regions is the alluvium of the Indo-Gangetic plain, stretching from Bihar on the east through the United Provinces and the Punjab to Sind on the western coast. In parts of Bihar, wheat is grown on high moisture retaining loams without irrigation. In Oudh, wells supplement the rainfall, while in the western districts of the United Provinces, canal water is commonly employed in wheat growing. In the Punjab, the crop is largely watered from perennial and inundation canals while, in Sind, inundation from the Indus takes the place of the monsoon. The predominant features of the wheat tracts of the plains are the alluvial character of the soil and the occurrence of some form of irrigation. The second great wheat growing tract in India is found in the Peninsula on the black cotton soils of the Central Provinces and Bombay. Here irrigation is the exception and most of the wheat is grown on the moisture left in the soil after the previous monsoon.

Besides moisture and soil, another factor in Indian wheat production is of importance. This is the limited growth period. Wheat can only be sown with safety as soon as the temperature falls sufficiently for germination to take place and for the seedlings to develop. Any attempt to lengthen the growth period by early sowing leads to the partial or entire destruction of the seedlings by heat. The duration of the growth period is equally limited by temperature at harvest time. The Indian wheat crop ripens under a rapidly ascending temperature, often accompanied by hot, dry winds. Any late crops dry up rather than ripen and the rapid advance of the hot season prevents the cultivation of late maturing wheats. The

growth period is shortest in Bombay and Central India and longest in the Punjab and North-West Frontier Province.

The main directions in which Indian wheat can be improved are two—yield and quality. The limited growth period, the frequent shortness of the water-supply, and the fact that in many tracts the moisture retaining capacity of the wheat soils is not great, all indicate that moderate yielding wheats are likely to be the most profitable to the grower over an average of seasons. Higher yielding wheats can be grown with safety to a very limited extent in places where the retentive power of the soil is considerable and where the growth period is longer than the average. Compared with the wheats of Western Europe, where the growth period is long, the rainfall well distributed and the standard of agriculture far higher, the wheats of India are only moderate yielders. Generally speaking, the season is too short in India for the growth of such high cropping wheats as those of France and England. As yield is determined by the length of the growth period and the average water-supply, the plant-breeder in increasing the amount of wheat grown soon reaches the limit imposed by these conditions. In the improvement of the quality of Indian wheat, however, there is much greater scope for the breeder. In general, the wheats of the country have poor grain qualities, both from the milling aspect and also from the point of view of bread-making. Some Indian wheats do not mill well while all those exported have a reputation for producing weak flour.

The method adopted in this investigation has been to compare, as regards consistency, absolute weight, nitrogen content, and milling and baking qualities, several pure lines, of widely different quality, grown at various centres. The stations have been selected so as to include as many as possible of the most important wheat tracts of the Indo-Gangetic plain as well as a few places representative of the black cotton soils of Peninsular India. In the present paper, the behaviour of Pusa 12 at a large number of stations is the chief subject dealt with.

II. The Influence of Environment on Grain Quality.

Six Pusa wheats were employed in the environment experiments of 1911-12. Three of these (Nos. 4, 12, and 22) are selections and three (Nos. 107, 108, and 110) are hybrids. All are white wheats of good quality and would be described as strong, free milling sorts.

The fourteen stations at which these wheats were grown are representative of the general agricultural conditions of the Indo-Gangetic plain and of the soils of Central India. These stations, which are indicated on the map at the end of this paper, were as follows :—

Stations on the Gangetic Alluvium.

1. *Pusa.* This station is situated on the older alluvium in North Bihar, a tract in which wheat is grown without irrigation on high moisture retaining loams containing about 30% of calcium carbonate.

2. *Partabgarh.* This station represents the alluvial tract of Oudh where wheat is chiefly grown on well-irrigation.

3. *Cawnpore.* This centre is typical of the wheat tract known as the Middle Doab, where wheat is grown on strong alluvial loams with canal irrigation.

4. *Meerut and Aligarh.* These are duplicate stations, typical of the large alluvial canal irrigated tract known as the Upper Doab, where wheat is an important cold weather crop. The agricultural conditions at these two centres closely resemble those of the neighbouring Muzaffarnagar District.

STATIONS IN THE INDUS VALLEY.

6. *Gurdaspur*. This centre is situated in the submontane tract of the Eastern Punjab, where wheat is largely grown as a dry crop without irrigation.

7. *Lyallpur*. This station is typical of the canal irrigated tract known as the Chenab Colony, which produces a large proportion of the wheat exported from Karachi. Overwatering the wheat crop is a common spectacle in the Chenab Colony where the general standard of cultivation is below that practised by the best cultivators in the Eastern Punjab and in the Upper Doab.

8. *Mirpurkhas*. This station is situated in Sind where wheat is largely grown on the moisture left after inundation from the Indus. The wheat production of this area is likely to increase very considerably when it is commanded by perennial canals.

BLACK SOIL STATIONS.

9. *Raipur and Tharsa*. These stations are situated in the Eastern portion of the Central Provinces where wheat is grown on the moisture left in the black soils after the monsoon.

11. *Hoshangabad*. At this centre, which is situated in the Narbada Valley in the west of the Central Provinces, the black soils of Central India are seen to perfection. Wheat is perhaps the most important crop in this tract and irrigation is exceptional.

12. *Orai*. The agricultural conditions of this Bundelkhand station resemble those of the Central Provinces mentioned above. The soil is, however, not true black cotton soil and the wheat crop round Orai is watered to some extent by canals.

SOUTH BIHAR STATIONS.

13. *Dumraon*. This station is situated in South Bihar to the south of the Ganges and outside the Gangetic alluvium. The soil is sandy and possesses little moisture-retaining capacity. In consequence, even with irrigation, the yields of grain and straw are small.

14. *Bankipore.* This centre is also to the south of the Ganges where the soil is not true Gangetic alluvium. It is a dark, heavy, moisture-retaining clay, not unlike some of the soils of Peninsular India.

The soil and moisture conditions at these fourteen stations vary greatly as well as the general standard of agriculture. It is no exaggeration to say that these stations represent the entire range as regards soils and agricultural practice in India at the present time and every gradation between dry cultivation, in the monsoon-fed areas, and canal irrigation, in tracts which would otherwise be desert. The selection of these stations was purposely made in order to determine how a wheat with good grain qualities would behave under such widely differing conditions. In the previous paper, tables were published giving the agricultural details relating to the preparation for wheat, the seed rate in general use, and the amount of water given after sowing. General information relating to the production of the wheat crop can also be found in *Wheat in India.*[1]

After the harvest of 1912, twenty-eight samples of wheat, grown at the fourteen stations mentioned above, were selected for complete milling and baking tests and Mr. Humphries' report is given in full below.

REPORT BY MR. A. E. HUMPHRIES (PAST PRESIDENT OF THE INCORPORATED NATIONAL ASSOCIATION OF BRITISH AND IRISH MILLERS) ON TWENTY-EIGHT SAMPLES OF WHEAT FROM THE INDIAN CROP OF 1912 SENT TO ENGLAND IN 1913.

"In continuation of similar work performed by me in several previous seasons, I have examined, cleaned, conditioned and milled separately twenty-eight sample lots of wheat sent me by Mr. Albert Howard, Imperial Economic Botanist and Mr. H. Martin Leake, Economic Botanist to the Government of the United Provinces,

[1] Howard & Howard, *Wheat in India*, 1909, pp. 1—46.

and I have baked the flour produced from each lot by at least three different methods, so that I may be able to form a confident opinion as to their respective commercial merits on the markets of the United Kingdom.

In previous reports, I have discussed various technical details, and, therefore, need not herein do more by way of preamble than reiterate a few definitions. Conditioning is a term applied to the adjustment of the physical condition of wheat, whereby an optimum separation of branny husk from kernel can be made in milling. Where Indian wheats are concerned, it includes an addition of water varying widely in degree according to the nature of the variety. Some kinds are described as free-milling, because the separation of such wheat in milling into its various commercial constituent products can be effected easily, other kinds are described by the expressive term woolly because separations in milling are effected with great technical difficulty. The colour of the resulting flour depends to a considerable extent upon the facility with which the necessary separations in milling can be effected. The term strength, applied to flour, means its capacity for yielding large shapely loaves. Stability indicates the facility with which the baker can handle large masses of dough. Yield of bread, which must not be confounded with strength, is the measure of the quantity of bread which can be produced from a given quantity of flour. Good flavour implies a moistness and sweetness in the taste of bread at least one day old. The term good colour, applied to flour, indicates its whiteness or brightness. A wheat which is translucent may be strong, but translucency is not a true index of strength. Nor is it correct to use hard and strong as correlated terms, for some hard wheats are weak; some soft wheats are strong. A wheat is said to be red or white according to the colour of its skin. The term red really implies various shades of brown; the term white various shades of yellow. A red skin may cover an endosperm of good colour; a white skin may cover an endosperm of poor colour. Many red wheats are strong; most white wheats are weak, but

colour of skin is one Mendelian unit, quality of endosperm is another; and a white wheat may be of maximum strength; a red wheat may be quite weak. The relative darkness of the medium and lower grades of flour is due principally to the presence of comminuted bran, and it is obvious that red bran particles will discolour flour much more than those from a white bran. As a rule, white wheats are more inclined to woolliness than red ones; but the former can behave perfectly in milling, and the ideal wheat will probably be a white one.

Wheats Received.

The wheat growing districts of India may be grouped as follows:—

1. The Ganges Valley.
2. The Indus Valley.
3. The Black Soils of Central India.

I have received twenty-eight sample lots, and these can be grouped as follows:—

	Ganges Valley.	*Indus Valley.*	*Black Soils.*
Pusa 12 from	Pusa.	Gurdaspur.	Raipur.
	Bankipore.	Lyallpur.	Tharsa.
	Dumraon.	Mirpurkhas.	Orai.
	Partabgarh.		
	Cawnpore.		
	Aligarh.		
	Meerut.		
Pusa 22 from	Pusa.	Lyallpur.	
	Partabgarh.		
	Cawnpore.		
	Orai.		
	Aligarh.		
	Meerut.		
Pusa 4 from	Pusa.		Tharsa.
			Hoshangabad.
Pusa 107 from	Pusa		Tharsa.
,, 108	Pusa.		Tharsa.
,, 110	Pusa.		

I have, in previous seasons, tested many varieties grown in India and from among them have selected for commendation those

known as Pusa 4, Pusa 12, and Pusa 22. I am very pleased to see that these varieties have now been grown at several places representing widely differing sets of natural conditions, so that I am now in a position to ascertain the effect of environment upon their qualities.

Methods of Testing.

When a new kind of wheat is offered to a buyer, he forms an opinion as to its merits upon its appearance, and he probably buys the first lot with no better guide to its intrinsic worth than its good or bad looks. Of course, an experienced buyer is better able to appraise the real value of good looks than a beginner. To the latter, a fine development and cleanliness may be all important: the former has learned to know that a fine exterior may cover many faults, and dirt, which can easily be removed, may nevertheless obscure real beauty. Even so, the best judges know quite well that their judgment in such a case may be faulty. Various methods of rapid and accurate testing have been suggested. For instance chewing has been recommended, and in certain cases for certain points of quality that rough and ready test is valuable: but it is useless or worse than useless in other cases, and obviously it would not be used in the case I have pre-supposed, if the wheats were coated with dirt of unknown origin. I need not labour the point that cleanliness and a good appearance must in any and all cases materially affect the price which a wheat will realize in our markets. But there are other points which in most cases will militate against a new kind of wheat at the outset of its commercial existence. A miller has to learn how to treat it in conditioning and milling, so as to secure optimum results, and he has to ascertain definitely not only how it will behave in the bakehouse when used by itself but how it will behave when blended with many other wheats in various proportions. All this takes much time and trouble and the inevitable mistakes cost money, so that a buyer is not likely to pay a full price for the first few lots of a new kind of wheat. But if he finds by many and various tests and by long

experience that it has great intrinsic merits and can be relied upon to vary in its qualities within small limits only, the reputation of the wheat will grow and its relative commercial value will increase. So it may easily happen that a new wheat of great intrinsic worth, arriving in unattractive guise from a district which has hitherto produced wheat of poor quality, may realize at the outset relatively poor prices on our markets and have to overcome slowly the well or ill-founded prejudices due to its appearance, or even to its geographical source of origin, yet in time *the same wheat, even in the same unfortunate or deplorable guise*, may win its way to the real esteem of buyers, and command relatively high prices in our markets. On the other hand, a wheat of beautiful appearance, coming from likely quarters, may, in time, because it is nondescript in quality, possessing no outstanding merit of real importance, recede in relative commercial value and leave the beginner or outsider wondering why merchants and millers have such apparently curious ideas as to the value of wheats.

In recent years, a good deal of work has been done by chemists to ascertain the ultimate cause or causes of quality in wheat, but it is true even now to say that they are unable to state with precision, in terms of their own science, the characteristics of wheat which are the ultimate causes of, or at any rate are correlated with, good baking qualities. For present purposes, I have confined my enquiries, as to the quality of the samples sent me, to their appearance, and to their behaviour in the mill and bakehouse under commercial conditions.

Cleaning. Almost all of the sample lots arrived in first rate condition. The wheats from Lyallpur and Gurdaspur, however, were dirty and Pusa 12 from Bankipore was very weevilly, so these wheats had to be specially cleaned.

Conditioning. From previous experience, I was aware that to obtain flour and bread of optimum quality, some Indian wheats

had to contain after 'conditioning' a relatively low, others a high or even a very high percentage of water. Although I had in previous years tested these varieties, I have made a few tests this year to settle in my own mind how the samples should be conditioned.

Baking. I have used the baking method with which I regularly and continuously test flours for commercial purposes. The flour from each of these Indian sample lots has been tested in at least three ways :—

A. In this set, the flour obtained from each wheat indicated was used without admixture of any other flour, and in making the dough, flour, water, salt and yeast were the only ingredients.

B. This set was made in the same way as A except that in each case a highly diastatic malt extract was added in making the dough, in a proportion equal to 0·2 per cent. of the flour used.

C. Because British millers very rarely use Indian wheats alone, I have in this set made a mixture of flours, using in each case one-third of a straight run flour made from No. 2 Northern Manitoba wheat of the 1912 crop, and two-thirds of the flour from each Indian wheat indicated. I have for this set used the B baking method except that the proportion of malt extract was reduced to 0·14 per cent. of the total flour used in each case.

Pusa 12.

This may be described as a long berried, white wheat inclined to be opaque. The berries are not really large, but in most cases are well developed and may be described as of good size.

The three groups of this wheat, judged by appearance, differ from each other, principally as regards hue. Those from the Ganges Valley and from the Black Soil Districts are of yellow hue, those from the Indus Valley are different. It is difficult to describe the difference in words, but a miller will understand the phrase if I say they

are of a white or yellow colour with a grey hue. When I wa examining the samples for the first time, I did not know th geographical position of Gurdaspur or Mirpurkhas, and I was ver greatly interested when I discovered that these places are in th Indus Valley. The hue to which I am referring appears, therefore, t be characteristic of the district so far as this variety is concerned, and it is a good point, for to me it is indicative of good quality. It is very unfortunate that the Lyallpur sample, and, in lesser degree, the Gurdaspur lot are so dirty. That blemish detracts very seriously from their appearance, and it would militate against their commercial value, especially when the wheat is first introduced to our markets in commercial quantities. In a previous season, I received a sample lot of wheat grown at Raipur, which possessed a most attractive appearance and was in fact of very superior quality. This Pusa 12 sample grown at Raipur in 1912 has a very peculiar appearance. It contains a few grains of a pink hue, and other grains which have a black discoloration at the germ end of the berry. If that wheat had been offered to me in commerce, I should have bought only a small quantity at a low price, because its unusual appearance would have left me in great doubt concerning its real worth. The Tharsa wheat is smaller in berry than the average Pusa 12, but British millers would not object to it for that reason. The remaining Black Soil lot, Orai, is very pale and therefore unattractive in appearance to millers who have to make strong flour.

In recent years, a great deal has been heard of strength in wheat, and in some connections that point is of great importance, but it is easy to exaggerate its importance in other connections. So although an increase in the strength of Indian wheat is desirable, it is far from being the only point of quality which buyers will take into consideration. For instance, Pusa 12, grown at Orai and Bankipore, has the appearance of weakness, but in other respects are good, well-grown wheats. The Dumraon lot, although it contains a considerable proportion of translucent grains, does not appear to be strong, nevertheless it is a beautiful sample of wheat. I need not attempt to describe the appearance of each lot in detail, but

taking into consideration all points of quality, I should place them, according to appearance, in the following order :—

1. Aligarh.
2. Meerut.
3. Cawnpore.
4. Dumraon.
5. Partabgarh.
6. Mirpurkhas.
7. Pusa.
8. Gurdaspur.
9. Orai.
10. Tharsa.
11. Bankipore.
12. Lyallpur.

From the foregoing list I have omitted Raipur, for the reason already mentioned, but if I were compelled to place it, I would bracket it equal to its sister lot Tharsa. Furthermore, when I was examining the samples for the second time, I appraised them differently. It then seemed to me desirable to put the grey hued ones, Mirpurkhas, Gurdaspur, and Lyallpur into a separate group, for I began to suspect that they were in fact of better quality than their appearance at first sight would lead one to expect. However, as I am at this moment setting out a sequence of relative merit according to appearance only, I have left the list as I first made it. Accordingly, Lyallpur is certainly at the bottom. It is a dingy, dirty looking lot, and the germ end of the berry appears to be swollen in a way which one would expect to find if the earliest stages of germination had been passed. This small point of appearance is characteristic of all Pusa 12 samples, but it is specially noticeable in the Lyallpur sample.

In conditioning and milling, all these wheats behaved satisfactorily except the Bankipore lot, and as that was badly weevilled on its arrival in England, its inferior behaviour in the mill is explained. The miller's note on the Tharsa lot is that it "milled about the same as dry English." The lots from the Indus districts

(Mirpurkhas, Lyallpur and Gurdaspur) behaved quite well at these stages. After conditioning, they were more uniformly mellow than the Ganges Valley lots, but they required the same percentage of water as those to yield optimum separations.

The baking trials provided an interesting surprise ; for by each of the methods described hereinbefore as A, B and C, the Indus Valley lots showed a substantial superiority in strength and stability over the others, and the Black Soil lots a slight but still appreciable superiority in strength over those from the Ganges Valley. Having regard to my previous experience, it was no surprise to find that even the last named were distinctly superior in these respects to the ordinary Indian wheats of commerce, Karachi, Calcutta, or Bombay. Of course, it must be remarked that I have been handling in these trials small quantities of wheat on an experimental scale, but as the results set out in the following tables are in conformity throughout with this verdict, my opinion as to stability and strength is a confident one, but because it is impossible to obtain optimum results as regards colour of flour and bread in testing such small lots, I do not want to say much concerning that point of quality, but it was obvious that, in this respect also, the real worth of the Lyallpur lot is at variance with its appearance, for the colour of the crumb was very good, fully equal to any other of the series and superior to most of them.

The following tables will best put on record the results obtained in the bakehouse as to 'stability' and 'strength' of the thirteen lots of Pusa 12.

It has for many years seemed to me easier to record one's opinion in marks than in words, and a long and varied experience has enabled us to express ourselves in this way with facility, but it must be understood that the figures do nothing more than express the baker's and my own opinion of the relative merits of the samples concerned on the points of quality specified. We may sometimes aid our judgment by measuring some of the loaves, but essentially the markings are based on the impression conveyed to our mind

by the senses of touch and sight : the method by which bakers in commerce almost invariably judge the flours they use. Indeed, I would like to emphasize the point, that I have deliberately chosen to test, according to commercial methods, all the Indian wheats I have handled on an experimental scale, for it seems to me of great importance to apply, even to these small lots, the methods which will be used in commerce in handling shiploads ultimately. Certain forms of laboratory work may assist the miller and baker to obtain optimum results in the mill and bakehouse, and I am very keen on seeking to apply such knowledge to commerce, but in the present state of knowledge such work may sometimes mislead, and for the purposes now in view, I have carefully applied well-known commercial methods and based my judgment upon them exclusively.

Ganges Valley.

	STABILITY.				STRENGTH.			
	Baking method.				Baking method.			
	A.	B.	C.	Average.	A.	B.	C.	Average.
Cawnpore	80	84	85	83	79	84	88	84
Pusa	82	88	88	86	80	86	83	83
Aligarh	80	84	85	83	82	82	86	83
Meerut	80	84	85	83	82	82	86	83
Bankipore	78	84	86	83	76	83	87	82
Partabgarh	80	84	82	82	80	80	84	81
Dumraon	78	82	84	81	76	79	79	78
AVERAGE	80	84	85	83	79	82	85	82

Black Soils.

	STABILITY.				STRENGTH.			
	Baking method.				Baking method.			
	A.	B.	C.	Average.	A.	B.	C.	Average.
Tharsa	80	88	85	84	84	86	89	86
Raipur	78	84	88	83	75	82	92	83
Orai	78	84	88	83	75	80	84	80
AVERAGE	78	85	87	83	78	83	88	83

Indus Valley.

	Stability.				Strength.			
	Baking method.				Baking method.			
	A.	B.	C.	Average.	A.	B.	C.	Average.
Mirpurkhas	82	86	86	85	85	90	92	89
Lyallpur	82	88	88	86	85	86	92	88
Gurdaspur	78	86	88	84	84	85	88	86
Average	81	87	87	85	87	91	91	88

The flour from the ordinary Indian wheat of commerce, Choice White Karachi, baked by itself would, according to the scale used, obtain, say, 70 marks for stability and 70 for strength ; No. 2 Northern Manitoba, 1912 crop, would get, say, 92 and 95 respectively, so my opinion as to the relative merits of these wheats as regards stability and strength may be stated in the following summary :—

	Stability.	Strength.
No. 2 Northern Manitoba, 1912 crop	92	95
Pusa 12, Indus Valley	87	87
Pusa 12, Black Soils	85	83
Pusa 12, Ganges Valley	84	82
Choice White Karachi	70	70

It will be seen that in this summary, I have used the figures concerning the Pusa 12 wheats, from the B set of trials.

Before I make any comments on these baking results, I should like to put side by side the two sequences of merit relating to these Pusa 12 wheats, one based on appearance, in which all points of quality are taken into consideration, the other based on baking trials in which the only points of quality considered are stability and

strength. For the latter sequence, the marks based on the three sets of baking trials A, B and C are used.

Appearance.	*Strength & Stability.*
Aligarh.	Lyallpur.
Meerut.	Mirpurkhas.
Cawnpore.	Gurdaspur.
Dumraon.	Tharsa.
Partabgarh.	Cawnpore.
Mirpurkhas.	Pusa.
Pusa.	Aligarh.
Gurdaspur.	Meerut.
Orai.	Raipur.
Tharsa.	Bankipore.
Raipur.	Partabgarh.
Bankipore.	Orai.
Lyallpur.	Dumraon.

Although, of course, I did not expect, having regard to what they purport to be, to get the same order of merit in both cases, the differences between the two sequences are striking, and I have made some enquiries with a view to ascertaining the causes or explanation of the discrepancies.

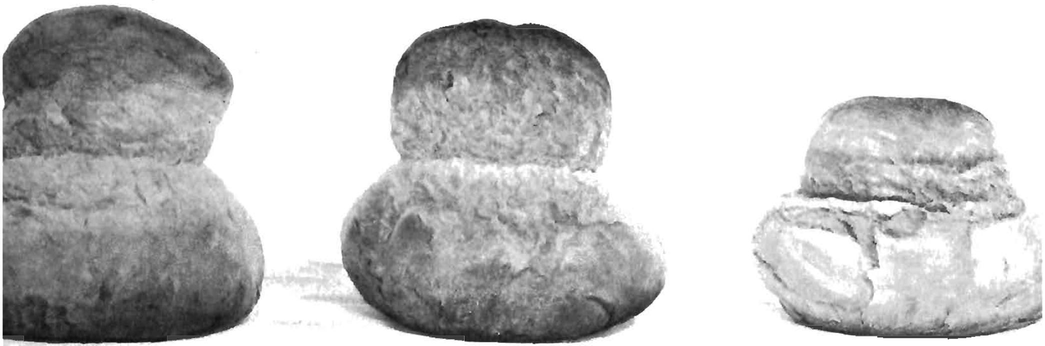
The most extraordinary difference concerns the Lyallpur lot, certainly at the bottom of the list when judged by appearance, at the top so far as strength and stability are concerned. I have already said that this lot as regards colour of "crumb" was very good, fully equal to any other of the series and superior to most of them, but on this point of quality, I have this further important remark to make. Bread produced from Manitoba wheat has at its best a beautiful grey white colour, that produced from Choice White Karachi is intensely yellow, and relatively bad. The Pusa 12 from Lyallpur yielded bread similar to the Manitoba in this respect. Here, therefore, is a case to which my remarks under the heading "Methods of Testing" apply. No miller would buy the first lot, or few first lots of it, except at a low price; he might well hesitate to spend time and trouble in making trials to ascertain its intrinsic merits. Surely something can be done to improve its looks.

Another striking result is the position of the Indus Valley wheats in the second sequence. I shall be very interested in seeing in later seasons how other varieties behave when tested in a similar

way. For present purposes, it is sufficient to say, that so far as quality is concerned, Pusa 12 seems to suit the Indus Valley. If this wheat be extensively grown in that district, it will probably command sooner or later higher prices in our markets than the Choice White and Red Karachi now so largely used in this country. If its yield per acre of grain and straw be no higher than that obtained from the varieties now commonly grown in the district, the relative increase in value per quarter should commend Pusa 12 to growers; if it will also yield increased crops of grain and straw on an average of seasons, it should replace existing varieties within a few seasons; but it is only right to add that no likely increase in the price per quarter will compensate for a substantially diminished yield. I shall therefore be much interested in seeing the returns as to yield of grain and straw.

The Dumraon lot was particularly well developed, and might be described as a really beautiful sample. Nevertheless, it was relatively 'weak.' I find on enquiry that it was grown on over-irrigated sandy loam, which might account for the baking result. It is necessary, however, to point out that this lot, though it is at the bottom of the list as regards bakehouse results, is nevertheless much better than the ordinary Indian wheat of commerce (Karachi, Calcutta or Bombay) as regards stability and strength. In this connection I should like to say that the Bankipore lot is stronger than its looks and record would lead one to expect. I understand that it was grown after rice, on land which had been over-irrigated for that crop, and it seems that so far as strength is concerned, it was made to appear worse than it is by that treatment.

It will be seen from the tables that the 'strongest' earned 89 and the 'weakest' 78 marks for strength. I am surprised that the difference is not greater. Some years ago, we grew wheat from the same seed on several typical soils in England, and found the differences greater than those with which we are now dealing. However, I have made enquiries to ascertain whether any of the districts represented in these trials are unlikely to grow wheat for



[M]anitoba (No. 2 Northern) Pusa 12 (Gurdaspur). Choice White Karachi.

LOAVES FROM CANADIAN AND INDIAN WHEATS.

export, and I find that Bankipore and Dumraon are in that category and that Tharsa, Raipur and Orai, if they furnish any at all for that purpose, are likely to provide only relatively small quantities. It, therefore, appears from my informatiou that the likely exporters of substantial quantities are as follows. Alongside each name, I have placed its marks for 'strength' (average of A, B, C methods of baking).

By Karachi.		*By Calcutta.*	
Lyallpur ..	.. 88	Pusa ..	.. 83
Mirpurkhas ..	.. 89	Partabgarh ..	.. 81
Gurdaspur ..	.. 86		
Cawnpore ..	.. 84		
Aligarh ..	.. 83		
Meerut ..	.. 83		

If the growers and merchants of the Indus Valley will send their wheats to our markets in a cleaner state than the samples I have received from Lyallpur and Gurdaspur, I see no reason why, for commercial purposes, the produce from the districts named in the Karachi list should be sold here separately, but if the wheat from the Punjab, when shipped on a commercial scale, will be as unsightly as the two samples named, the produce from the other districts should be marketed separately. The former will require much time to establish the reputation they deserve in this country, but for the latter with their fine appearance, enhanced prices may be expected on their first arrival.

It is obvious that there is no reason for marketing the Pusa and Partabgarh wheats separately.

In Bulletin 22, issued in 1911 by the Agricultural Research Institute, Pusa, a coloured photograph of three loaves baked by me was included, and I was asked to provide a similar photograph showing a loaf made from the Lyallpur lot of Pusa 12, alongside a loaf produced from No. 2 Northern Manitoba and another from Choice White Karachi. I had made several trials with this Lyallpur wheat, and, in doing so, had used up the whole of the lot sent me, so as the Gurdaspur wheat, of which I had some left, was similar though slightly inferior to the Lyallpur, I made a further test and had the photograph taken which is reproduced herewith. It was

coloured by hand to show the characteristic differences in the colour of the crusts. I need hardly say that the better coloured crusts are not only thinner and better in all respects than the grey one, but they give the loaves a much more appetising appearance.

Pusa 22.

Of this variety, I received sample lots from seven places. It is a round berried wheat of attractive appearance, similar to Canadian Fife in grain shape and in its behaviour in the mill. This in its category is high praise, for Fife whether it be grown in Canada, England or Germany, or whether it is represented by its Australian progeny Comeback, or its English child Burgoyne's Fife, is ideal in its behaviour in the mill. To get optimum results, I found it desirable to raise the water content of these samples to a high figure. In this connection, I would like to remark that the use of water in wheat conditioning, has been reduced to a science. To obtain successful results, close attention must be paid to details, more particularly as to quantity and time, and amateur efforts in applying water to wheat may be as harmful to it, as the unskilled use of water at spas may be injurious to the human system.

I append, in this case also, the two sequences, one constructed on appearance only for all points of quality, the other on baking results for stability and strength only. In these cases, I found that the use of diastatic malt extract did very little good, so my opinion as to baking results is based on trials made with flour, water, salt and yeast only, in other words, the method known as 'A' in the Pusa 12 trials is the only one referred to in this connection.

Appearance.	*Stability & Strength.*	
Pusa.	Lyallpur ..	.. 84
Aligarh.	Pusa ..	.. 84
Cawnpore.	Meerut ..	.. 84
Meerut.	Cawnpore ..	.. 79
Partabgarh.	Partabgarh ..	.. 79
Orai.	Orai ..	.. 79
Lyallpur.	Aligarh ..	.. 79

Here we have the same striking difference concerning Lyallpur and the remarks I made on that point in the case of Pusa 12 apply

here also. The only other striking difference in these two series concerns the Aligarh lot. It certainly was weevilled on its arrival here, and that may be the indirect cause of a falling off in baking value, but apart from that, our work on English wheat has shown that a given soil may grow a relatively strong sample of one variety and under identical conditions a relatively weak sample of another variety, which simply means in effect. that we have to provide for each environment a variety or varieties in the highest degree suitable for it. I understand, however, that mainly for agricultural reasons, this wheat is not likely to be extensively grown, and I may, therefore, dismiss it with these few remarks.

The Pusa lot is of particularly attractive appearance and the Orai wheat though very pale is nevertheless hard.

Pusa 4.

I am at present particularly interested in this variety because it has got beyond the experimental stage and I have received a small sample of a large quantity grown in 1913 on a commercial scale in Bihar.[1] I have shown this sample to several millers and merchants, who all, with one consent, say it is very fine looking wheat. One miller, who tested it by a comparatively new but secret laboratory method, praised it very highly, and said such wheat "will never go begging." Some of a cautious turn of mind, well acquainted with ordinary Indian wheats, refrain from expressing an opinion concerning its real merits until they have tested it under commercial conditions.

I have received for milling and baking tests three sample lots grown in 1912, respectively, at Pusa, Tharsa and Hoshangabad. The last named is the best of the three, judged by appearance and is very fine wheat beautifully grown. The Pusa sample has the blemish of a black spot on the germ end of the berry which it had in previous years, and in addition this year, a similar black spot in the crease at the opposite end of the berry. This is not a very detri-

[1] This sample was grown on the Hathowria Estate in the Darbhangha District.

mental fault, but if it can be removed it will be an improvement Apart from that, this lot is not so well-grown as the same wheat raised in previous seasons at Pusa. The Tharsa lot contains some unsound grains. It lacks brightness and appears to have been substantially damaged by unfavourable climatic conditions. However, all three lots behaved very well in the bakehouse, and in the markings for stability and strength were quite close together. The flours from the Hoshangabad and Tharsa lots behaved like typical London milled flours, the Pusa lot was tougher in the dough than the others, and to some extent resembled the flours made from American or Canadian spring wheat.

Pusa Nursery Lots.

In addition to the foregoing, I received the following sample lots; two lots of Pusa 107, one grown at Pusa, the other at Tharsa; two lots of Pusa 108, one from each of these places, and one lot of Pusa 110 grown at Pusa. Pusa 108 is a round berried wheat. The grains of the Pusa lot are small in size and those of the Tharsa lot still smaller, but that is not a serious fault. The former is wholly hard and wholly translucent, a very fine looking lot. The latter is not so bright or so translucent, and appears to have suffered from bad weather. Both behaved very well in the bakehouse and yielded bread of beautiful appearance.

Pusa 107 is a much larger berried wheat, quite as large as Pusa 12. This variety as grown at Pusa may also be described as wholly hard and wholly translucent, is particularly well-grown, and is in fact a lovely sample of wheat. The Tharsa lot also appears to have suffered from bad weather. In this case the relative inferiority in appearance of the Tharsa lot corresponds with the baking result, but the bread from it was good, that from the Pusa lot very good.

Pusa 110 is a long berried grey white wheat, is almost wholly translucent and quite hard. This lot (from Pusa) is a very nice sample of wheat, although the blemish of the dark spot found in Pusa 4 occurs in this variety also. It behaves quite well in the bakehouse.

Wheats grown at Pusa.

I have this year received in all sample lots of six varieties grown at Pusa, and having regard to their appearance and to the bakehouse results, I should place them in the following order of merit :—

Pusa	108	very close together.
"	4	
"	110	
"	107	
"	12	level.
"	22	

They are all fine wheats, and there is no great difference between the best and the worst of them.

Wheats from Tharsa.

I place the four lots from Tharsa in the following order of merit :—

Pusa 12
" 107
" 4
" 108

but there is very little difference between the best and the worst of them.

Summary.

It has again been demonstrated that wheats of the highest class can be grown in India on several kinds of soil, and on land which has been irrigated. It has been shown that the high excellence of quality possessed by wheats grown at Pusa in previous seasons was not due to environment or agricultural practice, for the same varieties of wheat have yielded still better results elsewhere. It is interesting to note that this high excellence of quality was found existing in wheats indigenous to India, and that in the Pusa Nursery varieties, the progeny appear to possess intact the great strength of the strong parents. I have no doubt that any or all of the wheats tested will realize, some at once, some later, relatively higher prices on our markets than the existing Indian wheats of commerce. If these new varieties yield no more grain and straw per acre than those ordinarily grown, their extended distribution as seed is desirable ;

if, in addition, the new varieties will yield greater quantities of grain and straw than those ordinarily grown, the position of the Indian grower will be greatly improved, and the propagation of the new kinds should be pressed forward."

WEYBRIDGE, ENGLAND,
3rd October, 1913.

A. E. HUMPHRIES.

Some exceedingly interesting results are to be found in the above report which it is now proposed to deal with briefly. The first relates to the importance of milling and baking tests in environment experiments with wheat. In the case of the Pusa 12 sample grown at Lyallpur, the report shows that a miller of great experience, who had tested this variety in previous years, was entirely misled by the external appearance of the badly grown and harvested sample. Great flour strength and good milling qualities are therefore liable to be masked by the effects of poor cultivation and overwatering. This experience with the Lyallpur sample is of the greatest value as it shows that if the Indian cultivator is to obtain immediately the greatest financial return for his labour he must not only grow a wheat with good quality but this wheat must be well-grown so that it at once takes the eye of the buyer. The appearance of the sample is therefore a most important matter in the work of introducing to advantage a new grade of wheat on the Home markets.

The general results obtained with Pusa 12 at the thirteen stations confirm and extend those obtained in 1910-11. These are summed up in Table 1, which also gives the consistency, absolute weight and nitrogen percentage of the various samples. It will be seen that the nitrogen percentage of Pusa 12 is, on the whole, not very high. The actual tests bring out the point that no matter what the agricultural conditions were, the milling and baking

TABLE 1.

Comparative value of Pusa 12 grown at various stations in 1910-11 and 1911-12.

Where grown.	Consistency.						Weight of 1,000 grains in grammes.		Nitrogen Percentage.		Baker's Marks. 1911-12.		Order of Merit.			
	1910-11.			1911-12.									1910-11.		1911-12.	
	Soft.	Inter.	Hard.	Soft.	Inter.	Hard.	1910-11.	1911-12.	1910-11.	1911-12.	Stability.	Strength.	On Appearance.	In Baking tests.	On Appearance.	In Baking tests.
Lyallpur	88	12	0	90		10	35·53	40·70	1·61	1·99	86	88	Fifth	Fifth	Thirteenth	First
Mirpurkhas	—	—	—	9	59	32	—	38·25	—	2·31	85	89	—	—	Sixth	First
Gurdaspur	—	—	—	7	71	22	—	40·87	—	1·96	84	86	—	—	Eighth	Third
Tharsa	—	—	—	0	71	29	—	31·03	—	1·95	84	86	—	—	Tenth	Fourth
Cawnpore	0	47	53	0	70	30	40·81	39·10	1·38	1·74	83	84	First	First	Third	Fifth
Pusa	3	80	17	0	69	31	42·64	38·75	2·25	2·02	86	83	Second	Second	Seventh	Sixth
Aligarh	4	69	27	1	57	42	37·25	44·37	2·17	1·84	83	83	Third	Third	First	Seventh
Meerut	7	92	31	0	54	46	35·03	43·90	1·51	1·74	83	83	—	—	Second	Eighth
Raipur	—	—	—	18	55	27	—	36·95	—	2·29	83	83	—	—	Tenth	Ninth
Bankipore	43	46	11	26	56	18	40·78	37·32	1·75	1·67	83	82	Fourth	Fourth	Twelfth	Tenth
Partabgarh	55	27	18	11	61	28	38·03	40·68	1·56	1·62	82	81	—	—	Fifth	Eleventh
Orai	30	42	28	0	75	25	38·68	42·67	1·66	1·56	83	80	—	—	Ninth	Twelfth
Dumraon	86	13	1	0	65	35	38·15	39·33	1·75	1·58	81	78	—	—	Fourth	Thirteenth

qualities were little influenced by environment. Flour strength and milling qualities were not in the least destroyed by transferring a dry crop wheat raised at Pusa in the extreme east of the wheat-growing area of India to North-Western India, or to the black soils of Central India. Indeed, the wheat was improved by this treatment, as the best results were obtained at Lyallpur, Mirpurkhas, and Gurdaspur, in the Indus Valley and at Tharsa in Central India.

A single grade of white wheat of improved quality can therefore be grown over a very large part of the wheat producing area of India. If the yield of grain and of *bhusa* (straw) of this wheat under cultivators' conditions is satisfactory over these areas, then a great step in advance will have been made. That this step has been accomplished will be evident when it is remembered that this wheat is now being distributed to cultivators in the Punjab, United Provinces, Bihar, and Central Provinces. Over a very wide range of conditions and of soils, both under dry cultivation and with canal and well irrigation, this wheat has done uniformly better than the local sorts when grown by the cultivators themselves. It is now only a matter of time and of organization for this variety to replace the existing crop over large tracts and for its produce to influence the Indian wheat trade. Besides its good yielding power, Pusa 12 stands out in the field from the country wheats as a red chaffed, beardless wheat with strong straw among bearded white chaffed kinds mostly characterized by very weak straw. This fact is of considerable advantage in the work of replacing the country wheats by the new variety.

The milling and baking results obtained with the samples of Pusa 12 grown in the Indus Valley and also on the black soils prove that there is no longer any reason why grain quality should be ignored in the work of improving the wheats grown in these two areas. In the first place, the performance of this wheat when grown by cultivators shows that yield and quality can be combined in the same variety. In the second place, these areas, which now produce only poor quality wheats, have been shown to be capable of growing samples of the same class as the best grades of Manitoba wheat.

It has been demonstrated in previous papers that all the Punjab wheats tested up to the present are of poor quality and of the same class as the grade known as Choice White Karachi. In like manner, the white *pissi* wheats of the black cotton soils which have been tested are far inferior to Pusa 12. From the results obtained by the cultivators with this wheat in the Eastern Circle of the Central Provinces, it is exceedingly likely that it will replace the wheats now grown over large areas of the Central Provinces. To be conclusive, the trials will have to be made under actual cultivators' conditions and on a sufficiently large scale.

In the case of Pusa 22, the results of the last two years are summed up in Table 2. This wheat was selected from the local Bihar mixtures and in good years yields very fine looking samples. Its weak straw and liability to rust will prevent its ever being taken up by cultivators.

The results of the tests of the other Pusa wheats are also of interest. The details relating to the consistency, absolute weight and nitrogen percentage are given in Table 3. Pusa 4 is a white wheat with good straw which is exceedingly early and which can ripen an attractive looking sample on the minimum of soil moisture. For this reason it is being widely distributed to cultivators in Bundelkhand where the soil often contains too little moisture to ripen the local wheats. In Bihar, this variety, on account of its rapid growth, strong straw and limited foliage has proved a suitable cover crop for Java indigo, and it is hoped to establish this wheat in North Bihar in sufficient quantities for export as an improved grade. The results of the tests of Nos. 107, 108 and 110 are of interest as they show that in the work of breeding improved varieties it is possible to transmit unimpaired the high quality of one parent. These three types were obtained by crossing Pusa 6 and Muzaffarnagar. In the case of No. 110, an improved Muzaffarnagar has resulted with stronger straw, red chaff and a high quality grain. Where an improved bearded wheat is required on the Gangetic alluvium this variety is well worth a trial.

TABLE 2.

Comparative value of Pusa 22 grown at various stations in 1910-11 and 1911-12.

Where grown.	Consistency.						Weight of 1,000 grains in grammes.		Nitrogen Percentage.		Baker's Marks.	Order of Merit.			
	1910-11.			1911-12.								1910-11.		1911-12.	
	Soft.	Inter.	Hard.	Soft.	Inter.	Hard.	1910-11.	1911-12.	1910-11.	1911-12.	1911-12.	On Appearance.	In Baking tests.	On Appearance.	In Baking tests.
Lyallpur	91	9	0	14	69	17	25·42	29·61	1·74	2·24	84	Fifth	Fifth	Seventh	First
Pusa	5	34	61	0	24	76	30·12	33·85	1·97	1·91	84	Second	Second	First	Second
Meerut	5	30	65	1	35	64	25·58	30·85	1·79	2·03	84	—	—	Fourth	Third
Cawnpore	0	25	75	0	39	61	34·80	31·55	1·91	1·83	79	First	First	Third	Fourth
Partabgarh	53	29	18	0	36	64	29·70	32·99	1·63	1·76	79	—	—	Fifth	Fifth
Orai	1	33	66	1	67	32	26·25	34·77	1·83	1·68	79	—	—	Sixth	Sixth
Aligarh	3	45	52	0	24	76	28·58	32·76	1·55	1·76	75	Second	Second	Second	Seventh

TABLE 3.

Comparison between Pusa 4, 107, 108, 110, *grown at Pusa and in the Central Provinces,* 1910-11 *and* 1911-12.

Name of wheat and locality.	CONSISTENCY.						Weight of 1,000 grains in grammes.		Nitrogen percentage.	
	1910-11.			1911-12.						
	Soft.	Inter.	Hard.	Soft.	Inter.	Hard.	1910-11.	1911-12.	1910-11.	1911-12.
Pusa 4, Pusa ..	0	9	91	3	53	44	45·67	39·31	2·25	2·26
,, 4, Raipur ..	0	50	50	—	—	—	45·30	—	1·79	—
,, 4, Hoshangabad	—	—	—	1	40	59	—	37·76	—	1·97
,, 4, Tharsa ..	—	—	—	12	69	19	—	38·58	—	2·04
,, 108, Pusa ..	—	—	—	0	2	98	—	31·07	—	2·39
,, 108, Tharsa ..	—	—	—	4	72	24	—	29·06	—	1·88
,, 107, Pusa ..	—	—	—	0	4	96	—	38·49	—	2·35
,, 107, Tharsa ..	—	—	—	16	51	33	—	35·10	—	2·05
,, 110, Pusa ..	—	—	—	0	15	85	—	34·69	—	2·25

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